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# MAINTAIN, ENHANCE AND IMPROVE RELIABILITY OF CALIFORNIA'S ELECTRIC SYSTEM UNDER RESTRUCTURING

*Prepared For:*  
**California Energy Commission**  
Public Interest Energy Research Program

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**Lawrence Berkeley  
National Laboratory**

**CERTS**  
CONSORTIUM FOR ELECTRIC RELIABILITY TECHNOLOGY SOLUTIONS

**PIER FINAL PROJECT REPORT**

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## Preface

The Public Interest Energy Research (PIER) Program supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace.

The PIER Program, managed by the Energy Commission conducts public interest research, development, and demonstration (RD&D) projects to benefit the electricity and natural gas ratepayers in California. The Energy Commission awards up to \$62 million annually in electricity-related RD&D, and up to \$12 million annually for natural gas RD&D.

The PIER program strives to conduct the most promising public interest energy research by partnering with RD&D organizations, including individuals, businesses, utilities, and public or private research institutions.

PIER funding efforts are focused on the following RD&D program areas:

- Buildings End-Use Energy Efficiency
- Industrial/ Agricultural/ Water End-Use Energy Efficiency
- Renewable Energy Technologies
- Environmentally Preferred Advanced Generation
- Energy-Related Environmental Research
- Energy Systems Integration

Maintain, Enhance and Improve Reliability of California's Electric System Under Restructuring is the final report for the Maintain, Enhance and Improve Reliability of California's Electric System Under Restructuring project contract number 150-99-003 conducted by the Consortium for Electric Reliability Technology Solutions. The information from this project contributes to PIER's Energy Systems Integration Program.

For more information on the PIER Program, please visit the Energy Commission's Web site at [www.energy.ca.gov/pier](http://www.energy.ca.gov/pier) or contact the Energy Commission at (916) 654-5164.

## **Abstract**

California's electric power system is in transition from one that has been centrally planned and controlled to one that will be increasingly dependent on competitive market forces to determine its operation and expansion. Electric networks pose unique challenges resulting from the need to match supply and demand in real-time and the rapid propagation of disturbances throughout the grid. Yet, the transition is incomplete and has led to, among other things, under-investment in grid infrastructure. These challenges are being exacerbated as the existing grid is called upon to support an increased number of market transactions.

This project was a five-year program of research and technology development aimed at maintaining and enhancing the reliability of California's interconnected power system by mitigating outages while increasing the system's flexibility for the market-based supply of electric service. The project was organized around five major research areas:

1. Grid of the Future
2. Real-Time System Monitoring and Control
3. Integration of Distributed Energy Resources
4. Reliability and Markets
5. Demand Response (Load as a Reliability Resource)

Each research area, in turn, encompassed multiple research tasks.

## **Executive Summary**

California's electric power system is in transition from one that has been centrally planned and controlled to one that will be increasingly dependent on competitive market forces to determine its operation and expansion. Ensuring the reliability of electric networks pose unique challenges resulting from the need to match supply and demand in real-time and the rapid propagation of disturbances throughout the grid. Yet, the transition is incomplete and has led to, among other things, under-investment in grid infrastructure. Hence, the challenges for ensuring reliability are being exacerbated as the existing grid is called upon to support an increased number of market transactions.

In 2000, Lawrence Berkeley National Laboratory (LBNL) on behalf of both the Consortium for Electric Reliability Technology Solutions (CERTS) and the Electric Power Research Institute (EPRI) initiated a multi-year program of research on electricity reliability issues and technology needs. The overall goal of the project is to research, develop and commercialize new methods, tools and technologies to protect and enhance the reliability of California's electric power system under the emerging competitive electricity market structures.

The project was organized around five major research areas:

1. Grid of the Future
2. Real-Time System Monitoring and Control
3. Integration of Distributed Energy Resources
4. Reliability and Markets
5. Demand Response (Load as a Resource)

Each research area, in turn, encompassed multiple research tasks.

The project was conducted in three stages. The first two stages were included in the structure of the original contract. The third stage was added through two amendments to the original contract that added new tasks to one or more of the research areas. More recently, CERTS has worked with the PIER Transmission Research Program to initiate new contracts and task orders that further extend and enhance the research in the areas first developed through this project.

### **Grid of the Future**

The objective of this area of research is to support PIER Research Development and Demonstration (RD&D) planning on topics related to electricity reliability. This scope was expanded by the Energy Commission to include an application of a new optimal power flow tool, and a strategic analysis and review of California transmission planning issues.

Three tasks were completed under this area of research:

Task 2.2.1 Optimal Technologies

Task 2.2.2 Scenario Analysis in Support of Transmission RD&D Planning

Task 2.2.3 Strategic Assessment of Transmission and Transmission Planning in California

### **Real Time System Monitoring and Control**



The overall objective of this area of research is to lay the groundwork for a transition in reliability management philosophy from that of today, which is based on passive readiness (with large, conservative, market-inhibiting safety margins), to that of tomorrow, which will be based on active anticipation and pre-emptive actions in response to impending system emergencies (with dynamic, consistently-set, safety margins). This transition, moreover, must be implemented in a manner that is fully consistent with and indeed supportive of the continuing maturation of competitive energy markets.

Eighteen tasks were conducted under the original contract (Tasks 2.3.1-18). Five tasks were conducted under the amendment to the contract (Task 2.9.1-5). The research conducted in this area was directed and managed separately by CERTS and EPRI.

The CERTS tasks involved installation of working prototypes for software tools that give CA ISO system operators a more rapid, accurate, and predictive view of the state of the entire West Coast interconnected power system and that allows them to more accurately assess the needs of the system, largely by more effectively using data that are already available, but that are currently under-utilized. CERTS also developed the interfaces and installed off-line tools that allow system operators to utilize highly specialized measurement data (called phasor measurements), which provide an exact picture of the state of key elements within the entire West Coast system, but which were previously not available to CA ISO. The original prototypes for these tools were developed by CERTS for the U.S. Department of Energy (DOE) Transmission Reliability program. CERTS also researched advanced concepts in real-time control to enable more reliable operation of the power system. The incremental approach undertaken by CERTS produced near-term deliverables that are of immediate use to CA ISO system operators, while at the same time laying the groundwork for future enhancements. Research along this general line has been continued with the addition of new tasks through separate, follow-on contracts with CERTS that are managed by the PIER Transmission Research Program.

The CERTS tasks included:

- 2.3.1 Supplier & Control Area Performance for AGC Frequency Response (formerly, Ancillary Services Monitoring, Tracking and Prediction Tool –Complementary Development and Testing to Meet CA ISO Requirements)
- 2.3.2 VAR Monitoring, Tracking and Prediction Tool – Complementary Development and Testing to Meet CA ISO Requirements
- 2.3.3 Post-Disturbance Assessment and Monitoring Workstation – Complementary Development and Testing to Meet CA ISO Requirements
- 2.3.4 Improved Stability Nomograms and Remedial Action Schemes Prototype Development and Testing
- 2.3.5 Improved Phasor Measurement Systems Operational and Support Procedures
- 2.3.6 Advanced Real-Time Control System Simulation and Prototype Demonstration and Testing
- 2.9.1 Reliability Adequacy Tools
- 2.9.2 CA ISO Security Coordinator Wide-Area Real Time Monitoring
- 2.9.3 WSCC/CA ISO Loop Flow Monitoring, Management, Near-Term Prediction, and Probabilistic Assessment
- 2.9.4 Validate and Improve Stability Nomograms and Remedial Action Schemes using Wide-Area Synchronized Phasor Measurements

The EPRI tasks involved support for software tools that allow CA ISO system planners to exchange additional information on system conditions seamlessly with neighboring

electric power systems. The tools establish these linkages through a common interface that facilitates information exchange among the proprietary energy management systems (EMS) operated by CA ISO and its neighbors. Having provided a mechanism to facilitate centralized collection and exchange of these data, EPRI also provided software planning tools that allow CA ISO planners to analyze these data to obtain a more comprehensive picture of the current state of the West Coast interconnected power system. This, more comprehensive view of the state of the system increases the accuracy of planning studies that are conducted in advance of system operation.

The EPRI tasks included:

- 2.3.7 Build and Maintain Station Diagrams (formerly: WSCC-wide Common Information Model Development and Testing)
- 2.3.8 Advanced Topology Estimator Program Development and Testing
- 2.3.9 WSCC-wide Security Monitoring Display Development and Testing
- 2.3.10 Feasibility Study on the Implementation of Wide Area Measurement Systems (WAMS) with CIM
- 2.3.11 Training and Installation of Load Forecaster
- 2.3.12 Interface OSI PI Historian to CIM
- 2.3.13 Operator Training Simulator
- 2.3.14 Integration of EPRI Transformer Rating Technology into Path 15 Dynamic Line Rating
- 2.3.15 Forward Markets Administration
- 2.3.16 STEMS: Real-Time Market Simulator
- 2.3.17 STEMS: Data Tools and User Interface
- 2.3.18 Network Reliability Project
- 2.9.5 Transfer Limit Application of Community Action Room to California ISO

The research conducted under this task, more so than any other aspect of the research conducted in this project, was developed explicitly to support the needs of CA ISO. CA ISO provided significant in-kind resources in support of the research, as well as all required hardware and software licenses. Each phase of the research was reviewed and closely coordinated with the development of the production-grade EMS at CA ISO.

The period of time over which this research was performed (1999-2005) was a tumultuous one for the California electricity system. Several tasks, following recommendations from CA ISO, and review and approval by the Energy Commission contract manager, were modified and re-scoped to remain focused on CA ISO's highest priorities, which evolved over time in response to both external events (e.g., collapse of the California Power Exchange (PX) in 2001) as well as internal events (e.g., acquisition and commissioning of a new energy management system starting in 2002).

### **Integration of Distributed Energy Resources**

The objective of this area of research is to create the technologies and control strategies needed to capture the full potential of distributed energy resources (DER) to improve the reliability of the California interconnected power system. This includes consideration of control systems, including the sensors and instruments necessary to gather intelligence for real-time power management, and dispatch or coordination among distributed generation resources. It also includes improved modeling techniques to better characterize the technologies and their impacts on the distribution (and ultimately the transmission) system. With correct placement and control, it should be possible to increase system reliability, lower the cost of power delivery, improve power quality, and reduce the environmental impacts of producing and transmitting electricity.

CERTS research in this area is organized around the concept of a DER microgrid. A microgrid is an integrated power delivery system consisting of interconnected loads and distributed energy resources, which as an integrated system can operate in parallel with the grid or in an intentional island mode. The integrated DER are capable of providing sufficient and continuous energy to a significant portion of the internal load demand. The microgrid possesses independent controls and can island with minimal service disruption.

The focus of the research is to advance the CERTS Microgrid concept to commercialization. The immediate objectives addressed in this contract have been to develop the concept and conduct supporting research to the point at which a controlled laboratory test bed demonstration can be conducted using full-scale micro-sources. Following the test bed demonstration, a field demonstration is envisioned. Research in support of this objective was conducted under two tasks: Task 2.4 and Task 2.7. The final selection of a laboratory and conduct of the test bed demonstration is being conducted under a separate Energy Commission PIER contract with CERTS (#500-03-024).

Four tasks were completed under the original scope of Contract #150-99-003:

Task 2.4.1 Proof-of-Concept for Microgrid Control

Task 2.4.2 Standard Power Electronic Interface

Task 2.4.3 Distributed Energy Resources (DER) Customer Adoption Model (formerly, Effects of Ancillary Services Market Participation on Customer Distributed Energy Resources (DER) Adoption)

Task 2.4.4 Planning and Technical Support for California DER Test Beds

Five tasks were completed under Amendment A of Contract #150-99-003:

Task 2.7.1 Microgrid Control

Task 2.7.2 Microgrid Test Bed Design and RFP (continuation of Task 2.4.4)

Task 2.7.3 Field Demonstration Planning

Task 2.7.4 DER Customer Adoption Model (continuation of Task 2.4.3)

Task 2.7.5 DER Transfer/Closeout

Research activities were closely coordinated with related activities sponsored by the U.S. DOE Transmission Reliability program.

## **Reliability and Markets**

The objective of this area of research is to ensure that a fair and transparent market for electricity and ancillary services will provide reliable energy efficiently to California energy consumers. The reliable operation of power systems depends critically on the availability of sufficient quantities of various reliability-related (or ancillary) services to the system operator. The ancillary service requirements of the California interconnected power system are based on the need to ensure compliance with NERC and WSCC requirements. As witnessed by the extraordinary market problems experienced by California during 2000 and 2001, achieving the appropriate balance between ideal economic market mechanisms and traditional utility operating practices is difficult.

CERTS research in this area is interdisciplinary, requiring expertise from the disciplines of both power system engineering and market economics. A major thrust of the research is focused on increasing the role of demand in contributing to the health and improved functioning of markets. This led, through the contract amendment, to

creation of an entire area of research (Task 2.8) devoted to the concept of load as a resource or demand response.

Three tasks were completed under the original scope of Contract #150-99-003:

Task 2.5.1 Utilization of Load as a Bulk-System Imbalance Energy and Ancillary Service Resource

Task 2.5.2 Comparing Alternative Approaches to Congestion Management (formerly, Identifying Ancillary Service Reserve Requirements vs. Total Generation / Load)

Task 2.5.3 CA ISO's Congestion Management Philosophy and Design

Research activities were closely coordinated with related activities sponsored by the U.S. DOE Transmission Reliability program.

### **Demand Response (Load as a Resource)**

The objective of this area of research is to develop new information to answer the following two questions:

- What can the State do to help build a real-time energy information, signaling, and response infrastructure that is flexible and simple enough so that it can address the next energy crises not only the last one?
- What are the most effective strategies (technology, tariffs, etc.) related to deploying a real-time demand responsiveness system that are cost-effective, require minimal end-user interaction yet are effective?

CERTS research in this area is a follow-on to the activities conducted under Task 2.5 but focused specifically on three demand-response (DR) areas directly related to California's electricity market: a) Determine the current status of California's DR capabilities for typical large commercial, semi-industrial and institutional (LCI&I) facilities; b) Assess customer response to tariffs and assess strategies to increase customer DR response; and c) Help determine what technology and systems are required by CA ISO so that it can manage a real-time, two-way signaling system.

Four tasks were completed under the amendment to Contract #150-99-003:

Task 2.8.1 Demonstrations and Case Studies for Large Commercial, Semi-Industrial and Institutional Buildings

Task 2.8.2 Customer Response to Day-Ahead Wholesale Market Prices: Case Study of RTP Program Experience in New York

Task 2.8.3 Developing a Research Agenda to Address the Utilization of Responsive Load as a Bulk Power System Reliability Resource

Task 2.8.4 Demand Response Demonstration

Research along this general line has been continued with the addition of new tasks through separate, follow-on Energy Commission PIER contracts with CERTS (#500-05-001), and with LBNL's Demand Response Research Center (#500-03-026), which are managed by the PIER Demand Response Program.

## Publication Table

Task #	Written Deliverable	Publication Type
<b>Task 2.2: GRID OF THE FUTURE</b>		
2.2.1	Operations Review of June 14, 2000 PG&E Bay Area System Events Using Aempfast Software	Technical Report: P500-03-085F
2.2.2	California's Electricity System of the Future Scenario Analysis in Support of Public-Interest Transmission System R&D Planning	Technical Report: P500-03-084F LBNL-52047
2.2.3	Planning for California's Future Transmission Grid - Review of Transmission System Strategic Benefits, Planning Issues and Policy Recommendations	Technical Report: CEC-500-2005-132
	California's Electricity Generation and Transmission Interconnection Needs Under Alternative Scenarios	Technical Report: P500-03-106
<b>Tasks 2.3 &amp; 2.9: REAL-TIME SYSTEM MONITORING AND CONTROL</b>		
2.3.1	Supplier and Control Area Performance Monitoring System	Technical Report: P500-03-086F
	Ancillary Services Performance, Tracking and Predictive Working Prototype Functional/Design Specification and Data Requirements	Functional Specification
	Suppliers and Control Area Performance for AGC, Frequency Response, and Ancillary Services – Design Specifications for CAISO	Functional Specifications
2.3.2	Real-Time Voltage Monitoring and VAR Management System©	Technical Report: P500-03-087F
	VAR Management – Functional and Design Specification for the California Independent System Operator (CAISO)	Functional Specification
	Real Time Voltage Monitoring and VAR Management System User's Guide.	User's Guide
2.3.3	Synchronized Phasor Measurements Applications User Guide	Technical Report: P500-03-088F
2.3.4	Nomogram Validation Application for CAISO Utilizing Phasor Technology - Functional Specification	Functional Specification
2.3.5	Synchronized Phasor Measurement Information Server: Architecture and Data Model	Summary Report
2.3.6	A New Scheme for Voltage Control in a Competitive Ancillary Service Market	Conference Proceedings
	Automatic On-line Controller for Coordinated Slow Voltage Control	Journal Article
	Transient Excitation Boosting by Using Remote Signals	Journal Article
	Designing the Next Generation of Real-Time Control, Communication and Computations for Large Power Systems	Journal Article

2.3.7	CAISO Station Displays	Technical Report: EPRI 1008723
2.3.8	Advanced Topology Estimator Project Summary	Technical Report: EPRI 1009380
2.3.9	Wide Area Security Monitoring Display for California ISO: Requirements Specification Document	Technical Report: EPRI 1008724
2.3.10	No Written Deliverable	
2.3.11	Customization of the EPRI Artificial Neural Network Short-Term Load Forecaster (ANNSTLF) and User Support for the California Independent System Operator (CA-ISO)	Technical Report: EPRI 1007506
2.3.12	No Written Deliverable	
2.3.13	No Written Deliverable	
2.3.14	Development of Path 15 Software	Technical Report: EPRI 1009280
2.3.15	Bidding Strategies for GENCO's in the Short-Term Electricity Market Simulator (STEMS)	Presentation
2.3.16	Agent-Based Simulation of an Automatic Mitigation Procedure	Technical Report
	Pushing Capacity Payments Forward: Agent-Based Simulation of an Available Capacity Market	Technical Report
2.3.17	No Written Deliverable	
2.3.18	California's Electricity Restructuring: The Challenge to Providing Service and Grid Reliability	Technical Report
2.9.1	No Written Deliverable	
2.9.2	No Written Deliverable	
2.9.3	WECC CAISO Specific Needs for Loop Flow Monitoring, Management, Near Term Prediction and Probabilistic Assessment, and Prototype Monitoring System Design	Summary Report: 500-2005-168
	Analysis and Estimation of Loop (Parallel) Flow in Wide-Area Interconnected Power Systems	Journal Article
	A State Estimation Technique Based Design of a Conceptual Market Tool for Accommodating Loop Flow	Journal Article
	Estimation of Unscheduled Flow and Contribution Factors Based on $L_p$ Norms	Journal Article
	An Estimation Technique to Assign Contribution Factors for Loop Flows in an Interconnected Power System	Journal Article

	A Linear Static Kalman Filter Application for the Accommodation of Unscheduled Flows	Journal Article
	Considerations For Implementing Tag Schedules in Transmission Circuits	Journal Article
	Shapely Values Based Cost Apportioning Technique to Accommodate Unscheduled Flows Among Utilities	Journal Article
<b>Tasks 2.4 &amp; 2.7: INTEGRATION OF DISTIBUTED ENERGY RESOURCES</b>		
2.4.1	Integration of Distributed Energy Resources: The CERTS MicroGrid Concept	Technical Report – P500-03-089F LBNL-50829
	MicroGrids	Conference Proceedings
2.4.2	Integration of Distributed Technologies - Standard Power Electronic Interfaces	Technical Report: P500-2005-119
	Integration of Distributed Technologies - Standard Power Electronic Interfaces	Interim Report
2.4.3	Modeling of Customer Adoption of Distributed Energy Resources	Technical Report: P500-03-094F LBNL-49582
	Distributed Energy Resources Customer Adoption Modeling with Combined Heat and Power Applications	Technical Report: P500-04-007 LBNL-52718
2.4.4	Behavior of Capstone and Honeywell Microturbine Generators during Load Changes	Technical Report: P500-04-021 LBNL-49095
	Review of Test Facilities for Distributed Energy Resources	Technical Report: P500-03-090F SAND2003-1602
	Microgrid Energy Management System	Technical Report: P500-03-091F ORNL/TM-2002/242
	Behavior of Two Capstone 30kW Microturbines Operating in Parallel with Impedance Between Them	Technical Report: CEC500-2005-052 LBNL-55907
	Energy Manager Design for Microgrids	Technical Report: CEC500-2005-051 LBNL-54447
	The CERTS Microgrid and the Future of the Macrogrid	Conference Proceedings, Technical Report: LBNL-55281
2.4.5	No Written Deliverable	
2.4.6	No Written Deliverable	

2.4.7	No Written Deliverable	
2.7.1	Microgrid: A Conceptual Solution	Conference Proceedings
2.7.2	No Written Deliverable: See Task 2.4.4	
2.7.3	No Written Deliverable	
2.7.4	No Written Deliverable: See Task 2.4.3	
2.7.5	No Written Deliverable	
<b>Task 2.5: RELIABILITY AND MARKETS</b>		
2.5.1	Review of Current Southern California Edison Load Management Programs and Proposal for a New Market-Driven, Mass-Market, Demand-Response Program	Technical Report: P500-04-022 LBNL 52866
	Spinning Reserve from Pump Load: A Technical Findings Report to the California Department of Water Resources	Technical Report: P500-04-006 ORNL/TM-2003/99
	Load as a Reliability Resource in Restructured Electricity Markets	Technical Report: P500-03-092F ORNL/TM2001/97 LBNL-47983
	Designing Forward Markets for Electricity to Meet the Needs of Customers	Conference Proceedings
	Using Weather Derivatives to Improve the Efficiency of Forward Markets for Electricity	Conference Proceedings
2.5.2	Congestion Management Requirements, Methods and Performance Indices	Technical Report: 500-2005-166
2.5.3	Methodology for Automatic Zone Creation/Merging/Partitioning	Technical Report: P500-03-093F
<b>Task 2.8: DEMAND RESPONSE (LOAD AS A RESOURCE)</b>		
2.8.1	Development and Evaluation of Fully Automated Demand Response in Large Facilities	Technical Report: CEC-500-2005-013
	Market Transformation Lessons Learned from an Automated Demand Response Test in the Summer and Fall of 2003	Conference Proceedings
	Machine to Machine (M2M) Technology in Demand Responsive Commercial Buildings	Conference Proceedings
	Measurement and Evaluation Techniques for Automated Demand Response Demonstration	Conference Proceedings



2.8.2	Customer Response to Day-ahead Wholesale Market Electricity Prices: Case Study of RTP Program Experience in New York	Technical Report: CEC500-2005-120 LBNL-54761
2.8.3	Demand Response Research Plan to Reflect the Needs of the California Independent System Operator	Technical Report: CEC P500-04-023
2.8.4	CERTS Demand Response Project Plan for Summer 2005 DR Test in SoCAL Distribution Circuit	Test Plan

## 1. Introduction

California's electric power system is in transition from one that has been centrally planned and controlled to one that will be increasingly dependent on competitive market forces to determine its operation and expansion. Ensuring the reliability of electric networks pose unique challenges resulting from the need to match supply and demand in real-time and the rapid propagation of disturbances throughout the grid. Yet, the transition is incomplete and has led to, among other things, under-investment in grid infrastructure. Hence, the challenges for ensuring reliability are being exacerbated as the existing grid is called upon to support an increased number of market transactions.

In 2000, LBNL on behalf of both CERTS and EPRI initiated a multi-year program of research on electricity reliability issues and technology needs. The overall goal of the project is to research, develop and commercialize new methods, tools and technologies to protect and enhance the reliability of California's electric power system under the emerging competitive electricity market structures.

The project supports the PIER program objective of improving the reliability and quality of California's electricity. It also supports the PIER program objective of improving energy cost / value of California's electricity.

CERTS was formed in 1999 to research, develop, and commercialize new methods, tools, and technologies to protect and enhance the reliability of the U.S. electric power system under the emerging competitive electricity market structure. The members of CERTS are the Electric Power Group (EPG), LBNL, Oak Ridge National Laboratory (ORNL), the Power Systems Engineering Research Center (PSERC),<sup>1</sup> Pacific Northwest National Laboratory (PNNL), and Sandia National Laboratories (SNL). LBNL manages the CERTS program office and served as the principal investigator for this project and as the administrator for the contract.

EPRI is a major subcontractor to LBNL for this project. EPRI was established in 1973 as an independent, non-profit center for electricity and environmental research.

The California Independent System Operation (CA ISO) is a major partner for the project. CA ISO was formed in 1996, as part of California's electricity restructuring legislation (AB 1890) to operate the transmission assets owned by Pacific Gas and Electric, Southern California Edison, and San Diego Gas and Electric. CA ISO is charged with ensuring reliability or "keeping the lights on."

The project was submitted to the Energy Commission PIER program as an unsolicited proposal. Following its creation in 2001, the PIER ESI program assumed formal coordination of the research.

This report summarizes all of the research activities conducted by the project. The report is accompanied by XVII, separately bound appendices that contain written deliverables that were prepared for individual tasks. Taken together, the report and

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<sup>1</sup> PSERC is a National Science Foundation Industry/University Collaborative Research Center that currently includes the Arizona State University, University of California at Berkeley, Carnegie Mellon University, Cornell University, Georgia Institute of Technology, University of Illinois at Urbana-Champaign, Iowa State University, Texas A&M, University of Wisconsin-Madison, and Washington State University.

appendices represent a complete record of the research that was conducted by the project.

The project was organized around five major research areas:

1. Grid of the Future
2. Real-Time System Monitoring and Control
3. Integration of Distributed Energy Resources
4. Reliability and Markets
5. Demand Response (Load as a Resource)

Each research area, in turn, encompassed multiple research tasks.

The project was conducted in three stages. The first two stages were included in the structure of the original contract. The third stage was added through two amendments to the original contract that added new tasks to one or more of the research areas. More recently, CERTS has worked with the PIER program to initiate new contracts and task orders that further extend and enhance the research in the areas first developed through this project.

The remainder of the report is organized as follows: First, the motivation and scope for each research area is described. Then, under each research area, individual tasks are described and organized using the task numbering articulated in the original contract and amendments. The task descriptions follow a common template. The structure of the template includes descriptions of the research motivation/significance, methods, and accomplishments, as well as cross-references to publications and other written deliverables (provided as separate appendices), related tasks in this contract, and follow-on work (e.g., research conducted through separate PIER contracts).

## **2. Grid of the Future**

The objective of this area of research is to support PIER RD&D planning on topics related to electricity reliability. This scope was expanded by the Energy Commission to include an application of a new optimal power flow tool and a strategic analysis and review of California transmission planning issues.

Three tasks were completed under this area of research:

Task 2.2.1 Optimal Technologies

Task 2.2.2 Scenario Analysis in Support of Transmission R&D Planning

Task 2.2.3 Strategic Assessment of Transmission and Transmission Planning in California

### Task 2.2.1 Optimal Technologies

**Summary** – This task demonstrated the application of a new optimal power flow tool through a post-hoc analysis of certain PG&E system conditions on June 14, 2000.

**Objectives** – The objective of this was task to evaluate Aempfast’s capabilities by applying it to circumstances in which a power system was under acute stress.

**Leverage/partners/co-funding** – CA ISO and PG&E provided historic system modeling data required to conduct the re-analysis and served as technical reviewers for the project.

**Approach** – Aempfast was used to review certain decisions CA ISO and PG&E made on June 14, 2000 regarding the amount of load shed needed to prevent a voltage collapse on the Bay Area System, the proper location for monitoring system voltage levels, and the correct voltage level trigger point for ordering emergency load shedding to prevent voltage collapse. The review assumed the availability and control only of system resources available to CA ISO and PG&E on that date.

**Accomplishments** –The study found that with the tools and the data then available to them, CA ISO and PG&E made appropriate decisions on June 14, 2000 regarding amount of load to be shed, system monitoring point, and voltage level at which to commence load shed. A key finding was that poor system distribution of reactive power (“Q”) resources, as well as of real power (“P”) resources, contributed substantially to the impending voltage collapse under June 14 loads. After optimization using Aempfast, the Bay Area System was stable not only under the June 14, 2000 loads but also under test loads of 130.4 MW applied over and above the June 14, 2000 load levels.

**Significance of Research** - The analysis indicated that the re-controlling measures could have fully supported system voltage stability, with some resources to spare, potentially avoiding need for any load shed under the generation and load conditions of that day.

**Follow on (if appropriate)** – PIER has sponsored two additional research projects that utilize Aempfast as part of a methodology that seeks to quantify the potential for increased network efficiency and improved performance from ideally-situated distributed energy resources and distribution-level topology reconfigurations.

#### **Project participants**

Roland Schoettle, Optimal Technologies

#### **Publications**

Hope, G., R. Schoettle, and R. Hammond. *Operations Review of June 14, 2000 PG&E Bay Area System Events Using Aempfast® Software*. P500-03-085F. October 2005.

[http://www.energy.ca.gov/pier/final\\_project\\_reports/500-03-085.html](http://www.energy.ca.gov/pier/final_project_reports/500-03-085.html)

### Task 2.2.2 Scenario Analysis in Support of Transmission R&D Planning

**Summary** – This task analyzed four possible future scenarios for the California electricity system to assess transmission research and development (R&D) needs, with special emphasis on prioritizing public-interest RD&D needs, using criteria developed by the Energy Commission.

**Objectives** – The objective of this task was to contribute to the formation of a PIER program on transmission by articulating a rationale and establishing scope for appropriate public-interest research on this topic.

**Leverage/partners/co-funding** – None.

**Approach** – The scenario analysis approach involves postulating multiple, alternative, internally consistent future states of the California electricity system. The time horizon for the analysis was the next five years. Four scenarios were developed that describe different possible evolutions of the California electricity system and identify transmission RD&D needs for each. The needs were reviewed using the PIER program criteria for supporting RD&D, which involved assessing the RD&D interests and capabilities of the players and stakeholders in the California electricity market.

**Accomplishments** – The highest priorities for public-interest RD&D – i.e., those that emerge as priorities in more than one scenario – include: 1) Real-time grid /asset monitoring and analysis tools for reliability management; 2) Advanced real-time control technologies and approaches; 3) Market design, monitoring, and analysis tools; 4) Transmission planning expansion tools and approaches; and 5) Public health, safety, and environmental issues.

**Significance of Research** – There is an immediate need to focus public-interest RD&D support on the identified activities, all of which relate to system reliability and market efficiency. Specifically, they all relate to market design, monitoring, and planning tools as well as advanced controls, areas where roles and responsibilities in California are still evolving and for which there is no existing, established RD&D process or funding mechanism. Thus, California public-interest energy RD&D funds are critical to address the lack of tools and technologies in these areas.

**Follow on (if appropriate)** – Subsequent to the report, PIER ESI created a Transmission Research Program. The scenario analysis was a key ingredient to the development of the PIER Five-Year Transmission R&D Plan. The Transmission Research Program has both continued existing and initiated new research in areas identified by this task as appropriate targets for public-interest RD&D.

#### **Project participants**

Joe Eto, Lawrence Berkeley National Laboratory  
John Stovall, Oak Ridge National Laboratory

#### **Publications**

Eto, J. and J. Stovall. *California's Electricity System of the Future Scenario Analysis in Support of Public-Interest Transmission System R&D Planning*. P500-03-084F. October 2003.  
[www.energy.ca.gov/pier/final\\_project\\_reports/500-03-084f.html](http://www.energy.ca.gov/pier/final_project_reports/500-03-084f.html)

### **Task 2.2.3 Strategic Assessment of Transmission and Transmission Planning in California**

**Summary** – This task involved the preparation of two technical reports on transmission and transmission policy issues for the state of California for use in the Energy Commission’s 2004 Integrated Energy Policy Report (IEPR) Update.

**Objectives** – To raise visibility of strategic transmission policy and planning issues by conducting analysis and introducing it into the Energy Commission’s 2004 IEPR Update process.

**Leverage/partners/co-funding** – None.

**Approach** – Two technical reports were prepared: 1) A review of the benefits from past transmission projects, and 2) A long-term resource assessment.

**Accomplishments** – The first report identified significant benefits from past transmission project, which were not considered at the time these projects were built. The second report established the critical role that transmission must play in California’s energy future.

**Significance of Research** – A sustainable framework for transmission planning and investment was not created as part of electricity industry restructuring. Yet, an adequate and well-managed transmission system is essential for reliability and enabling competition in wholesale electricity markets. This research contributes to recently initiated policy discussions in California to address this need.

**Follow on (if appropriate)** – CERTS has been tasked to support the Energy Commission’s 2005 Integrated Energy Policy Report on related transmission planning and operational issues.

#### **Project participants**

Vikram Budhraj, Jim Dyer, and Fred Mobasher, Electric Power Group

#### **Publications**

Budhraj, V., J. Dyer, S. Hess. *Planning for California’s Future Transmission Grid: Review of Transmission System, Strategic Benefits, Planning Issues, and Policy Recommendations*. CEC-500-2005-132. August 2005. [www.energy.ca.gov/pier/final\\_project\\_reports/CEC-500-2005-132.html](http://www.energy.ca.gov/pier/final_project_reports/CEC-500-2005-132.html)

Budhraj, V., F. Mobasher, M. Cheng, J. Dyer, E. Castaño, S. Hess. *California’s Electricity Generation and Transmission Interconnection Needs Under Alternative Scenarios: Assessment of Resources, Demand, Need For Transmission Interconnections, Policy Issues and Recommendations For Long Term Transmission Planning*. P500-03-106. November 2003. [www.energy.ca.gov/pier/final\\_project\\_reports/500-03-106.html](http://www.energy.ca.gov/pier/final_project_reports/500-03-106.html)

### **3. Real Time System Monitoring and Control**

The overall objective of this area of research is to lay the groundwork for a transition in reliability management philosophy from that of today, which is based on passive readiness (with large, conservative, market-inhibiting safety margins), to that of tomorrow, which will be based on active anticipation and pre-emptive actions in response to impending system emergencies (with dynamic, consistently-set, safety margins). This transition, moreover, must be implemented in a manner that is fully consistent with and indeed supportive of the continuing maturation of competitive energy markets.

Eighteen tasks were conducted under the original contract (Tasks 2.3.1-18). Five tasks were conducted under the amendment to the contract (Task 2.9.1-5). The research conducted in this area was directed and managed separately by CERTS and EPRI.

The CERTS tasks involved installation of working prototypes for software tools that give CA ISO system operators a more rapid, accurate, and predictive view of the state of the entire West Coast interconnected power system and that allows them to more accurately assess the needs of the system, largely by more effectively using data that are already available, but that are currently under-utilized. CERTS also developed the interfaces and installed off-line tools that allow system operators to utilize highly specialized measurement data (called phasor measurements), which provide an exact picture of the state of key elements within the entire West Coast system, but which were previously not available to CA ISO. The original prototypes for these tools were developed by CERTS for the U.S. Department of Energy (DOE) Transmission Reliability program. CERTS also researched advanced concepts in real-time control to enable more reliable operation of the power system. The incremental approach undertaken by CERTS produced near-term deliverables that are of immediate use to CA ISO system operators, while at the same time laying the groundwork for future enhancements. Research along this general line has been continued with the addition of new tasks through separate, follow-on contracts with CERTS that are managed by the PIER Transmission Research Program.

The CERTS tasks included:

- 2.3.1 Supplier & Control Area Performance for AGC Frequency Response (formerly, Ancillary Services Monitoring, Tracking and Prediction Tool –Complementary Development and Testing to Meet CA ISO Requirements)
- 2.3.2 VAR Monitoring, Tracking and Prediction Tool – Complementary Development and Testing to Meet CA ISO Requirements
- 2.3.3 Post-Disturbance Assessment and Monitoring Workstation – Complementary Development and Testing to Meet CA ISO Requirements
- 2.3.4 Improved Stability Nomograms and Remedial Action Schemes Prototype Development and Testing
- 2.3.5 Improved Phasor Measurement Systems Operational and Support Procedures
- 2.3.6 Advanced Real-Time Control System Simulation and Prototype Demonstration and Testing
- 2.9.1 Reliability Adequacy Tools
- 2.9.2 CA ISO Security Coordinator Wide-Area Real Time Monitoring
- 2.9.3 WSCC/CA ISO Loop Flow Monitoring, Management, Near-Term Prediction, and Probabilistic Assessment
- 2.9.4 Validate and Improve Stability Nomograms and Remedial Action Schemes using Wide-Area Synchronized Phasor Measurements



The EPRI tasks involved support for software tools that allow CA ISO system planners to exchange additional information on system conditions seamlessly with neighboring electric power systems. The tools establish these linkages through a common interface that facilitates information exchange among the proprietary EMS operated by CA ISO and its neighbors. Having provided a mechanism to facilitate centralized collection and exchange of these data, EPRI also provided software planning tools that allow CA ISO planners to analyze these data to obtain a more comprehensive picture of the current state of the West Coast interconnected power system. This, more comprehensive view of the state of the system increases the accuracy of planning studies that are conducted in advance of system operation.

The EPRI tasks included:

- 2.3.7 Build and Maintain Station Diagrams (formerly: WSCC-wide Common Information Model Development and Testing)
- 2.3.8 Advanced Topology Estimator Program Development and Testing
- 2.3.9 WSCC-wide Security Monitoring Display Development and Testing
- 2.3.10 Feasibility Study on the Implementation of Wide Area Measurement Systems (WAMS) with CIM
- 2.3.11 Training and Installation of Load Forecaster
- 2.3.12 Interface OSI PI Historian to CIM
- 2.3.13 Operator Training Simulator
- 2.3.14 Integration of EPRI Transformer Rating Technology into Path 15 Dynamic Line Rating
- 2.3.15 Forward Markets Administration
- 2.3.16 STEMS: Real-Time Market Simulator
- 2.3.17 STEMS: Data Tools and User Interface
- 2.3.18 Network Reliability Project
- 2.9.5 Transfer Limit Application of Community Action Room to California ISO

The research conducted under this task, more so than any other aspect of the research conducted in this project, was developed explicitly to support the needs of CA ISO. CA ISO provided significant in-kind resources in support of the research, as well as all required hardware and software licenses. Each phase of the research was reviewed and closely coordinated with the development of the production-grade EMS at CA ISO.

The period of time over which this research was performed (1999-2005) was a tumultuous for the California electricity system. Several tasks, following recommendations from CA ISO, and review and approval by the Energy Commission contract manager, were modified and re-scoped to remain focused on CA ISO's highest priorities, which evolved over time in response to both external events (e.g., collapse of the California Power Exchange (PX) in 2001) as well as internal events (e.g., acquisition and commissioning of a new energy management system starting in 2002).

**Task 2.3.1 Supplier & Control Area Performance for AGC Frequency Response**  
(formerly, Ancillary Services Monitoring, Tracking and Prediction Tool –  
Complementary Development and Testing to Meet CA ISO Requirements)

**Summary** – This task was discontinued following completion of a functional specification due to changes in the design of CA ISO’s Ancillary Services markets. Funding was re-programmed to support higher, CA ISO-identified priorities involved in extending Tasks 2.3.2 and 2.3.3.

**Objectives** – To demonstrate the Department of Energy (DOE) Ancillary Services Monitoring, Tracking and Prediction Adequacy Tool at the CA ISO. The application was intended to provide the CA ISO dispatchers with a tool to manage ancillary services requirements and supplies in accordance with North American Electric Reliability Council (NERC) guidelines.

**Leverage/partners/co-funding** – A prototype version of the tool was developed initially with funding from the DOE Transmission Reliability program.

**Approach** – The task involved developing additional functional requirements defined by the CA ISO, preparation of a prototype, and then factory and field testing of the prototype.

**Accomplishments** – A detailed functional specification was prepared and submitted to CA ISO for review. Following changes in CA ISO’s Ancillary Services markets, functional specifications were prepared for a direct follow-on focused on supplier’s and control area performance monitoring for Automatic Generator Control (AGC) and frequency (under Task 2.9.1).

**Significance of Research** – Ancillary services, which include regulation and contingency reserves, are required to ensure the reliable delivery of wholesale electricity. Prior to restructuring, these services were self-provided through the coordinated actions of vertically integrated generation and transmission operations. Restructuring of the electric power industry has led to re-formulation of certain ancillary services as market products and the creation of wholesale markets through which they are procured by the CA ISO from generators. This has led to the need by CA ISO for tools to monitor, track, and predict the provision of these services.

**Follow on (if appropriate)** – A follow-on to the original intent of this project, focused on performance monitoring for supplier’s and control area AGC and frequency response, was pursued under Task 2.9.1. A functional specification was prepared, but the project was subsequently discontinued following CA ISO decision to implement this functionality using in-house resources.

**Project participants**

Carlos Martinez and Jim Dyer, Electric Power Group

**Publications**

Martinez, C., J. Dyer, M. Skowronski. *Supplier and Control Area Performance Monitoring System*©. P500-03-086F. October 2003.

[www.energy.ca.gov/pier/final\\_project\\_reports/500-03-086f.html](http://www.energy.ca.gov/pier/final_project_reports/500-03-086f.html)

CERTS. *Ancillary Services Performance, Tracking and Predictive Working Prototype Functional/Design Specification and Data Requirements*. February 2000.

CERTS. *Suppliers and Control Area Performance for AGC, Frequency Response, and Ancillary Services – Design Specifications for CAISO*. January 2003.

### **Task 2.3.2 VAR Monitoring, Tracking and Prediction Tool – Complementary Development and Testing to Meet CA ISO Requirements**

**Summary** – The CERTS VAR Monitoring, Tracking, and Prediction Tool was created and installed at the CA ISO Alhambra control center. Successful implementation of this prototype tool led to an expanded implementation under Task 2.9.1.

**Objectives** – To demonstrate the Department of Energy (DOE) VAR Monitoring, Tracking and Prediction Tool at the CA ISO. The application provides the CA ISO dispatchers with the first-ever wide-area, multi-view, geo-graphic visualization tool to manage voltage and reactive power reserves in accordance with NERC and Western Electric Coordination Council (WECC) guidelines.

**Leverage/partners/co-funding** – A prototype version of the tool was developed initially with funding from the DOE Transmission Reliability program. Hardware for implementation of the prototype and technical support for the San Diego system model was provided by CA ISO.

**Approach** – The task involved developing additional functional requirements defined by the CA ISO, preparation of a prototype, and then factory and field testing of the prototype. CA ISO determined that the prototype test would be conducted using the system model for the San Diego region.

**Accomplishments** – A prototype tool was field tested at CA ISO's Alhambra control center using the CA ISO model for the San Diego power system. All functionalities were demonstrated. Under Task 2.9.1, the prototype was expanded to encompass the entire CA ISO system.

**Significance of Research** – Reactive power reserves are critical for preventing voltage collapse following power system disturbances. Following post-analysis of the 1996 blackouts on the west coast, WECC revised its guidelines for monitoring voltages and maintaining adequate reserves. The CERTS VAR monitoring, tracking, and prediction tool was developed to automate aspects of these guidelines. The prototype tool demonstrated the first-ever wide-area, multi-view, geo-graphic visualization of voltage profiles in support of reactive power monitoring.

**Follow on (if appropriate)** – Aspects of this work were completed under Task 2.9.1. In addition, follow-on projects, moving toward real-time application of the concepts underlying the VAR tool continue to be a core element of CERTS research in support of reliability management activities at CA ISO under the PIER Transmission Research Program.

#### **Project participants**

Carlos Martinez and Jim Dyer, Electric Power Group

**Publications**

Martinez, C., J. Dyer, and M. Skowronski. *Real-Time Voltage Monitoring and VAR Management System*©. P500-03-087F. October 2003.

[www.energy.ca.gov/pier/final\\_project\\_reports/500-03-087f.html](http://www.energy.ca.gov/pier/final_project_reports/500-03-087f.html)

CERTS. *VAR Management – Functional and Design Specification for the California Independent System Operator (CAISO) Version 1.1*. July 2003.

CERTS. *Real Time Voltage Monitoring and VAR Management System User's Guide*. November 2002.

### **Task 2.3.3 Post-Disturbance Assessment and Monitoring Workstation – Complementary Development and Testing to Meet CA ISO Requirements**

**Summary** – The DOE Post-Disturbance Assessment Workstation was installed at CA ISO, a method of receiving phasor measurement data for use in the Workstation was completed, and training on the use of the Workstation was provided. Aspects of this project were completed under Task 2.9.1.

**Objectives** – To make the DOE Post-Disturbance Assessment and Monitoring Workstation prototype usable by CA ISO operating engineer. The Workstation allows the CA ISO operating engineer to better anticipate potential reliability problems, based on the analysis of past problems, which have been recorded in great detail using phasor measurement data collected by recording devices throughout the Western Interconnection.

**Leverage/partners/co-funding** – The original phasor data measurement system in the Western Interconnection was installed by a DOE/EPRI/BPA/WAPA project in the early 1990's. The software analysis tools incorporated into the Workstation were developed by Bonneville Power Administration, Pacific Northwest National Laboratory, and Southern California Edison. The prototype post-disturbance workstation incorporating these tools was developed by DOE. Hardware for the installation was provided by CA ISO.

**Approach** – This task involved three major tasks. The first task involved working with WAPA and relevant WECC committees to provide access to phasor measurement data to CA ISO over the WECC Extra High-Voltage (EHV) data network. The second task involved developing, testing, and delivering a prototype workstation that incorporated three, previously developed software analysis tools, according to CA ISO specifications. The third task involved provision of training to CA ISO staff that use the Workstation.

**Accomplishments** – All three tasks were completed.

**Significance of Research** – Prior to this project, CA ISO did not have access to nor means for analyzing phasor measurement information. Phasor measurements are accepted within WECC as a principal means for calibrating transient stability models, including the analysis of planned and unplanned system disturbances. Phasor measurements were instrumental in diagnosing the causes of the 1996 west coast blackouts. As a result of this research, CA ISO now has enhanced its ability to participate in WECC transient stability modeling and analysis activities that determine safe operating limits for the WECC system.

**Follow on (if appropriate)** – This project represents CA ISO's first effort to acquire and utilize phasor measurement data. Aspects of this work were extended under Task 2.9.1. In addition, follow-on projects, moving toward real-time utilization of phasor data continue to be a core element of CERTS research in support of reliability management activities at CA ISO.

#### **Project participants**

Carlos Martinez and Jim Dyer, Electric Power Group  
John Hauer, Pacific Northwest National Laboratory  
Ken Martin, Bonneville Power Administration  
Bharat Bhargava, Southern California Edison

**Publications**

CERTS. *Synchronized Phasor Measurements - Applications User Guide*. P500-03-088F. October 2003. [www.energy.ca.gov/pier/final\\_project\\_reports/500-03-088f.html](http://www.energy.ca.gov/pier/final_project_reports/500-03-088f.html)

### **Task 2.3.4 Improved Stability Nomograms and Remedial Action Schemes Prototype Development and Testing**

### **Task 2.9.4 Validate and Improve Stability Nomograms and Remedial Action Schemes using Wide-Area Synchronized Phasor Measurements**

**Summary** – This task was discontinued following discussion with CA ISO staff. It is being re-examined in 2006, as part of a separate contract. Funding was re-programmed to support higher, CA ISO-identified priorities involved in extending Tasks 2.3.2 and 2.3.3.

**Objectives** – To define, develop and test improved Stability Nomograms and Remedial Action Schemes prototypes

**Leverage/partners/co-funding** – This activity relies on the availability of phasor measurements; see Task 2.3.3.

**Approach** – The task involved developing additional functional requirements defined by the CA ISO, preparation of a prototype, and then factory and field testing of the prototype.

**Accomplishments** – This task was originally proposed as task 2.3.4, but at CA ISO and Energy Commission direction, was postponed in order to provide funding for the Optimal Technologies study (see Task 2.2.2). The task was re-proposed, as task 2.9.4, as part of the contract amendment. Task 2.9.4 was again postponed at CA ISO request and is being considered under a separate follow-on contract.

**Significance of Research** – This application is intended to allow the CA ISO security coordinator to have a more dynamic and realistic assessment of safe operating limits for both current security stability nomograms and remedial action schemes. The realism is enhanced over current security nomograms and remedial action schemes due to the incorporation of new application algorithms based on phasor data. The algorithms using phasor measurements would complement and could eventually replace current systems using only SCADA data with more precise information on the actual state of the system for portions of the Western Interconnection grid, outside of California.

**Follow on (if appropriate)** – This follow on project has been approved and will be administered by the PIER Transmission Research Program under a separate contract in 2006.

#### **Project participants**

Carlos Martinez and Jim Dyer, Electric Power Group

#### **Publications**

CERTS. *Nomogram Validation Application for CAISO Utilizing Phasor Technology - Functional Specification*. April 2004.



### **Task 2.3.5 Improved Phasor Measurement Systems Operational and Support Procedures**

**Summary** – This task identified and provided technical support to CA ISO to improve the software and data communications systems used by CA ISO to receive phasor measurement data.

**Objectives** – To identify and outline the deployment and support procedures requirements associated with the utilization and support of phasor measurements.

**Leverage/partners/co-funding** – CA ISO provided all hardware required to implement the recommendations identified by the CERTS team.

**Approach** – The team identified and outlined the development and support procedures requirements associated with the utilization and support of phasor measurements. The procedures addressed both software and data communication subsystems. The team also investigated second generation requirements for Phasor Measurement Units (PMU), Phasor Data Concentrators (PDC), and real time control data communications. Data communication issues for future architectures with multiple PMUs and PDCs interconnected for real-time control purposes were also addressed. Other critical issues such as overall lower costs, hardware and software standardization and overall availability improvements were also addressed.

**Accomplishments** – A final report was prepared outlining the assessment and recommendations.

**Significance of Research** – As noted previously (see Task 2.3.3), prior to this PIER project, CA ISO did not have access to phasor measurement information. This project addressed the infrastructure-side of providing this access, in order to enable the software applications described in Tasks 2.3.3 and 2.3.4. In doing so, it has contributed to lowering the costs associated with expanding and managing the reliable expansion of current real time monitoring and control systems based on phasor measurements.

**Follow on (if appropriate)** – The work identified in and initiated through the project is the foundation for future CA ISO applications involving phasor measurements. See Tasks 2.9.2 and 2.9.4.

#### **Project participants**

Carlos Martinez and Jim Dyer, Electric Power Group

#### **Publications**

CERTS. *Synchronized Phasor Measurement System - Synchronized Phasor Measurement Information Server Architecture and Data Model*. July 2001.

### **Task 2.3.6 Advanced Real-Time Control System Simulation and Prototype Demonstration and Testing**

**Summary** – This project prepared several technical papers that begin to explore options for future wide-area, real-time control of the power system.

**Objectives** – To simulate and test wide-area, advanced real-time control systems incorporating real-time measurements, including phasor measurements.

**Leverage/partners/co-funding** – This activity has and continues to be leveraged by complementary research sponsored by the DOE Transmission Reliability program and by PSERC.

**Approach** – Initially, technical papers are being prepared to explore potential future real-time control schemes. Following discussion and review of these papers with CA ISO and relevant WECC members, scoping would begin to identify needed additional simulation and pre-demonstration activities. The simulation and test would be expected to incorporate phasor measurements, SCADA data and other control technologies to address wide area as well as local reliability problems and enhance overall system reliability. Ultimately, a controlled, likely small-scale demonstration would be identified as a first, demonstration step.

**Accomplishments** – Technical papers were published assessing the feasibility of several aspects of future wide-area real-time control applications. Slow controls, like voltage control and frequency control, were selected for study as they are easier to implement with today's technologies. The slow voltage control algorithm is being implemented by BPA.

**Significance of Research** – Real-time, active control of the power system based on advanced (and conventional) real-time measurements is a core element of the smart, switchable electricity grid of the future that can anticipate and respond automatically to emerging grid problems. Yet, wide-area controls of this type are currently unprecedented and conservatism in the industry means that acceptance is still some time away. This work and complementary work sponsored by the DOE Transmission Reliability program are necessary first steps toward gaining acceptance of these concepts, leading ultimately toward demonstrations, and ultimately commercial acceptance.

**Follow on (if appropriate)** – PIER Transmission Research Program and CERTS are working with CA ISO, California utilities, and WECC utilities to begin scoping first-ever demonstrations of real-time control applications based on phasor measurements.

#### **Project participants**

Anjan Bose, Washington State University

#### **Publications**

Nobile, E. and A. Bose. *A New Scheme for Voltage Control in a Competitive Ancillary Service Market*. Power Systems Computation Conference, Seville, Spain. June 2002.

Chen, Y. and V. Venkatasubramanian. *Automatic On-line Controller for Coordinated Slow Voltage Control*, IEEE Transactions on Power Systems. In press.

Chen, Y. and V. Venkatasubramanian. *Transient Excitation Boosting Based on Remote Signals*, IEEE Transactions on Power Systems. In press.

Tomsovic, K., D. Bakken, V. Venkatasubramanian and A. Bose. *Designing the Next Generation of Real-Time Control, Communication and Computations for Large Power Systems*. Proceedings of the IEEE, Vol.93, No.5, pp.965-979. May 2005.

### **Task 2.9.1 Reliability Adequacy Tools**

**Summary** – This task provided continuation funding for follow-on steps to Tasks 2.3.1, 2.3.2, and 2.3.3.

## **Task 2.9.2 CA ISO Security Coordinator Wide-Area Real Time Monitoring**

**Summary** – This activity was discontinued following discussions with CA ISO staff. Funding was re-programmed to support higher CA ISO-identified priorities under Task 2.9.1.

**Objectives** – To create a prototype for a single, integrated monitoring system for CA ISO security coordinators based on prior CERTS-developed prototypes.

**Leverage/partners/co-funding** – This project was to leverage work conducted previously under Task 2.3.2, 2.3.3, and 2.9.1.

**Approach** – Define and collect key operational data produced by CERTS-developed tools for CA ISO, including VAR Management (Task 2.3.2 and 2.9.1), Supplier's and Control Area AGC and Frequency Regulation (Task 2.9.1) and Phasor Measurement Monitoring (Task 2.3.3 and 2.9.1). Define new operational metrics or security performance indices that improve security coordinator's real time grid reliability monitoring and assessment capabilities. Prepare a functional specification. Factory and field test a prototype.

**Accomplishments** – This activity was discontinued following discussions with CA ISO staff.

**Significance of Research** – CERTS has developed and prototyped several new grid reliability management tools designed, individually, to expand monitoring, tracking, and prediction capabilities of CA ISO dispatcher's and security coordinators. This task is intended to design and test a prototype that integrated aspects of these functionalities into a single tool specifically targeted to the needs of security coordinators.

**Follow on (if appropriate)** – Continued development of the VAR management functionalities, as well as creation of a real-time phasor data monitoring capability under separate contracts.

### **Project participants**

Carlos Martinez and Jim Dyer, Electric Power Group

**Publications** – None.

### **Task 2.9.3 WSCC/CA ISO Loop Flow Monitoring, Management, Near-Term Prediction, and Probabilistic Assessment**

**Summary** – This activity was discontinued following discussions with CA ISO staff. A technical paper laying the groundwork for aspects of planned work was prepared. Funding was re-programmed to support higher CA ISO-identified priorities under Task 2.9.1.

**Objective** – To develop a prototype incorporating better methods for predicting loop flow that would give operators and operations management additional time to address the impacts of loop flow on the CA ISO system.

**Leverage/partners/co-funding** – This activity has been and continues to be leveraged by complementary research sponsored by PSERC.

**Approach** – The proposed approach was capture the electronic Tags now collected by WECC, combine them with real-time SCADA data, and conduct a simplified load flow analysis to assess loop flow impacts on the CA ISO system. This would involve short-term forecasting techniques to prepare look-ahead assessments of likely and potential loop flow impacts. A functional specification would be prepared, followed by factory and field testing of a prototype tool.

**Accomplishments** – Technical papers were prepared proposing new metrics to assist in characterization of loop flow and its impacts on system operations.

**Significance of Research** – Loop flow can be a significant and unavoidable constraint on real-time operations. Better prediction of loop flow conditions, linked to better assessment of their potential impacts, provides greater advance warning to operators, who can use this information to re-dispatch operations with greater confidence.

**Follow on (if appropriate)** – None. Discussions with CA ISO revealed that, between the time this work was first proposed and finally approved through a contract modification, CA ISO already had implemented some of these functionalities in-house.

#### **Project participants**

Carlos Martinez and Jim Dyer, Electric Power Group  
Gerald Heydt, Arizona State University

#### **Publications**

Heydt, G.T., S. Suryanarayanan. *WECC CA ISO Specific Needs for Loop Flow Monitoring, Management, Near Term Prediction and Probabilistic Assessment, and Prototype Monitoring System Design*. CEC-500-2005-168. November 2005.

[www.energy.ca.gov/pier/final\\_project\\_reports/CEC-500-2005-168.html](http://www.energy.ca.gov/pier/final_project_reports/CEC-500-2005-168.html)

Chakka S., S. Suryanarayanan, G.T. Heydt. *Analysis and Estimation of Loop (Parallel) Flow in Wide-Area Interconnected Power Systems*. Proceedings of the North American Power System Symposium, Tempe, AZ, pp. 176 - 180. October 14 – 15, 2003.

Suryanarayanan, S., R.G. Farmer, G.T. Heydt, S. Chakka. *Estimation of Unscheduled Flow and Contribution Factors Based on Lp Norms*. IEEE Transactions on Power Systems, V. 10, No. 2, pp. 1245 - 1246. May 2004.

Suryanarayanan, S., G.T. Heydt, R.G. Farmer. *A State Estimation Technique Based Design of a Conceptual Market Tool for Accommodating Loop Flow*. Proceedings of the 2003 North American Power Symposium, Rolla, MO, pp. 87 - 91. October 2003.

Suryanarayanan, S., G.T. Heydt, R.G. Farmer, S. Chakka. *An Estimation Technique to Assign Contribution Factors for Loop Flows in an Interconnected Power System*. Journal Electric Power Components and Systems, V. 32, No. 8, pp. 813 – 826. August 2004.

Suryanarayanan, S., G.T. Heydt. *A Linear Static Kalman Filter Application for the Accommodation of Unscheduled Flows*. IEEE Transactions of Power Systems Conference and Exposition, New York, NY, CD band 1-MIRA. October 10 – 13, 2004.

Suryanarayanan, S., D.C. Montgomery, G.T. Heydt. *Considerations for Implementing Tag Schedules in Transmission Circuits*. IEEE Transactions of Power Systems, V. 20., No. 1, pp. 523 - 524. February 2005.

Suryanarayanan, S., G.T. Heydt. *Shapely Values Based Cost Apportioning Technique to Accommodate Unscheduled Flows Among Utilities*. IEEE Transactions of Power Systems. In press.

**Task 2.9.4 Validate and Improve Stability Nomograms and Remedial Action Schemes using Wide-Area Synchronized Phasor Measurements**

**Summary** – See Task 2.3.4



**Task 2.3.7 Build and Maintain Station Diagrams** (formerly: WSCC-wide Common Information Model Development and Testing)

**Summary** – Aspects of CA ISO’s Energy Management System (EMS) network model were converted to a new format, called the Common Information Model (CIM), including creation of new station diagrams.

**Objectives** – To support the CA ISO’s conversion from an older EMS system to a newer one, which is compatible with CIM.

**Leverage/partners/co-funding** – CA ISO provided its original EMS network model that formed the basis for the conversion.

**Approach** – Software tools were developed and used to convert the original CA ISO EMS network model to CIM. The original software was developed to support a proprietary EMS format and the software was later upgraded to support the industry standard CIM XML format. One-line station diagrams were prepared in XML format and software tools were provided to facilitate modifications to them.

**Accomplishments** – The station one-line diagrams were generated from the network topology for many of the major stations in the CA ISO system. These station diagrams highlighted a number of errors in the topology database. During the course of this project, CA ISO required that their new EMS vendor also provide an automatic display generation tool.

**Significance of Research** – The Common Information Model is a vendor-independent format that facilitates data exchange among utility EMS’ and incorporation of advanced applications. This project demonstrated that the CA ISO station diagrams could be generated from the network topology model and laid out with less than one tenth of the manpower effort that has been required with traditional systems.

**Follow on (if appropriate)** – None.

**Project participants**

P. Hirsch, EPRI

R. Podmore, Incremental Systems

M. Robinson, PowerData Corporation

**Publications**

EPRI. *CAISO Station Displays*. TR-1008723. 2003.

### **Task 2.3.8 Advanced Topology Estimator Program Development and Testing**

**Summary** – An advanced topology estimator was demonstrated using 3 small test systems.

**Objectives** – A topology estimator develops a best estimate of the electrical connectivity of a power system network based on limited, and often bad, data. A better estimate improves the quality and accuracy of subsequent modeling and analysis that rely on this estimate.

**Leverage/partners/co-funding** – None.

**Approach** – There were two phases. Phase 1 identified single status errors and validated the feasibility using the simplified MW angle formulation for identification of topology errors. Phase II was extended to handle multiple interacting bad data due to breaker/switch status errors and MW measurement errors by using combinatorial search methods to determine the most probable combination of status and analog measurement errors. Tests were performed with alternate systems with 69, 102, and 562 buses; the CA ISO model was not provided in time for use in this project.

**Accomplishments** – The advanced topology estimator and MW angle estimator require less commissioning and maintenance effort compared to a conventional state estimator since they are not affected by errors in shunt reactor/capacitor status and MVAR sign reversals. The advanced topology estimator was integrated with a CIM database.

**Significance of Research** – Based on the results obtained to date, it appears technically feasible to commission and maintain the topology estimators and MW/angle state estimators from very small networks all the way up to large-scale networks that span entire interconnections.

**Follow on (if appropriate)** – None.

#### **Project participants**

P. Hirsch, EPRI

R. Podmore, Incremental Systems

M. Robinson, PowerData Corporation

O. Alsac and N. Vempati, Nexant, Inc

#### **Publications**

EPRI. *Advanced Topology Estimator Project Summary*. TR-1009380. 2004.

### **Task 2.3.9 WSCC-wide Security Monitoring Display Development and Testing**

**Summary** – This project was discontinued following CA ISO review of a draft functional specification.

**Objectives** – To develop and test a Western States Coordinating Council (WSCC) -wide security monitoring display at the CA ISO which could be used by all security coordinators and control areas operators in the WSCC.

**Leverage/partners/co-funding** – None.

**Approach** – Four steps were envisioned: 1) Development of detailed software requirements; 2) Creation of a comprehensive software design; 3) Construction of software and factory testing; and 4) Conduct of field integration and acceptance tests.

**Accomplishments** – A requirements specification document was prepared for review by CA ISO.

**Significance of Research** – N/A

**Follow on (if appropriate)** – None.

#### **Project participants**

P. Hirsch, EPRI

I. Sethu, BEST Systems, Inc.

#### **Publications**

EPRI. *Wide Area Security Monitoring Display for California ISO, Requirements Specification Document*. TR-1008724. 2003.

### **Task 2.3.10 Feasibility Study on the Implementation of Wide Area Measurement Systems (WAMS) with CIM**

**Summary** – This project was discontinued following initial discussions with CA ISO.

**Objectives** – To study the feasibility of a Wide Area Measurement Systems (WAMS) support to the WSCC-wide CIM data base with real-time data obtained from phasor measurements.

**Leverage/partners/co-funding** – None.

**Approach** – This task envisioned preparation of a feasibility study to define project objectives and approach, including examination of risks.

**Accomplishments** – N/A

**Significance of Research** – N/A

**Follow on (if appropriate)** – N/A

**Project participants**

P. Hirsch, EPRI

**Publications** – None.

### **Task 2.3.11 Training and Installation of Load Forecaster**

**Summary** – The EPRI Artificial Neural Network Short-Term Load Forecaster (ANNSTLF) was implemented at CA ISO with an overall accuracy (1.5%) that exceeded CA ISO's goal (2%).

**Objectives** – To improve the accuracy of short-term load forecasts prepared by CA ISO.

**Leverage/partners/co-funding** – CA ISO

**Approach** – The capabilities and performance of EPRI ANNSTLF were optimized for CA ISO. This involved: 1) developing a pre-filter software package to check historical load and weather data (and provide a means for the user to fix errors); 2) "training" ANNSTLF using three years of data; 3) optimizing the weighting factors for weather data; 4) adapting ANNSTLF to provide half-hour (rather than 1 hour) forecasts; and 5) providing training for CA ISO staff.

**Accomplishments** – EPRI ANNSTLF, as implemented at CA ISO, was demonstrated to be capable of meeting all requirements of short-term load forecasting. The overall accuracy of 1.5% or less exceeded CA ISO's goal of 2%, which is acceptable for daily system and market operations. The EPRI ANNSTLF results for peak load forecast for 1 and 2 days ahead were compared with the official CA ISO forecasts for same as published on their website. The results showed that a combined forecasting model of EPRI-ANNSTLF and the CA ISO forecaster would yield results superior to both. In this case the EPRI-ANNSTLF would be weighted at 0.9 and the CA ISO forecaster with 0.1.

**Significance of Research** – Load forecasting is an important part of power system planning and operation. The delivered CA ISO ANNSTLF is easy to use and update the hour and half-hour forecasts with minimal manual intervention.

**Follow on (if appropriate)** – Although CA ISO has decided not to use ANNSTLF, it is strongly believed that a combined forecast of ANNSTLF and the current CA ISO forecaster would provide California with an improved forecast that serves the entire market. CA ISO used ANNSTLF in parallel with its own load forecaster for a while and improved the load forecaster that it is using after seeing the quality of results from the ANNSTLF forecasts.

#### **Project participants**

P. Hirsch, EPRI

A. Debs, Decision Systems International

#### **Publications**

EPRI. *Customization of the EPRI Artificial Neural Network Short-Term Load Forecaster (ANNSTLF) and User Support for the California Independent System Operator*. TR-1007506. 2002.

### **Task 2.3.12 Interface OSI PI Historian to CIM**

**Summary** – A software tool to interface the OSI's PI database currently used by CA ISO with a Common Information Model (CIM) database was demonstrated.

**Objectives** – To develop and install an interface from CA ISO's OSI PI Historian to a CIM database.

**Leverage/partners/co-funding** – CA ISO provided the OSI PI Historian database that was used in the project.

**Approach** – A software tool was developed to interface the OSI's PI Historian standard Application Program Interface (API) with the Oracle CIM database as developed by Siemens. The functionality was demonstrated, but was not installed, following CA ISO's review.

**Accomplishments** – The functionality was demonstrated by using it to record and trend EPRI Operator Training Simulator (OTS) results.

**Significance of Research** – The CIM is a vendor-independent format that facilitates data exchange among utility EMS' and incorporation of advanced applications.

**Follow on (if appropriate)** – None.

#### **Project participants**

Peter Hirsch, EPRI

Robin Podmore, Incremental Systems

Marck Robinson, PowerData Corporation

**Publications** – None.

### **Task 2.3.13 Operator Training Simulator**

**Summary** – The EPRI Operator Training Simulator was installed at CA ISO.

**Objectives** – To provide CA ISO with a real-time simulator that can be used as a test bed for evaluating new applications and as an easy to use tool for training system operators.

**Leverage/partners/co-funding** – CA ISO training staff reviewed installation of OTS.

**Approach** – This project consisted of five phases. First, installation of the base line OTS at CA ISO, which provided the tools to: 1) Build and validate the CA ISO model; 2) Build the CA ISO station displays; 3) Build base case power flow solutions; and 4) Build OTS scenarios. Second, development of an OTS model for CA ISO. Third, provision of initial training and support to CA ISO staff. Fourth, preparation of a final report. Fifth, development of OTS scenarios.

**Accomplishments** – The first three phases of this task were completed. The fourth and fifth tasks were not completed because CA ISO was not able to provide a complete system model to the project team within the time frame of this research activity. A version of the OTS with a generic power system model was used by CA ISO staff in the summer seminar during 2003, 2004 and 2005. Over 100 operators from CA ISO and the Participating Transmission Owners were trained with the Generic PowerSimulator during each seminar. As a follow on to the CA ISO work, the Generic PowerSimulator has been used by other major RTOs and reliability councils including PJM, MISO, NYISO, SERC, FRCC, IMO and ERCOT for emergency operations training.

**Significance of Research** – Operating training simulators are important test beds for systems operators to use in evaluating and testing new applications and for training system operators.

**Follow on (if appropriate)** – None.

#### **Project participants**

P. Hirsch, EPRI

Robin Podmore, Incremental Systems Corporation

Marck Robinson, PowerData Corporation

A. Debs, Decision Sciences International

**Publications** - None.

### **Task 2.3.14 Integration of EPRI Transformer Rating Technology into Path 15 Dynamic Line Rating**

**Summary** – A dynamic thermal software model that was previously developed and tested for the California Path15 power transmission interface was extended to include the Gates 500-/230-kV power transformer that is also a critical part of Path 15.

**Objectives** – To demonstrate how, through the application of monitoring instruments and complex numerical models, study results allow increased power flow and increased system reliability.

**Leverage/partners/co-funding** – Significant prior EPRI work on dynamic thermal rating of transmission equipment. The power transformer models were extensively tested and refined prior to this application.

**Approach** – The task involved adaptation of a sophisticated power transformer thermal model algorithm (“PTLOAD” developed by EPRI as part of the DTCR technology package). This approach avoids the need for development and extensive testing of a new power transformer thermal rating algorithm, and permits modeling of the interface in minimal time at minimal cost.

**Accomplishments** – The completed model takes into account a double line outage (DLO) where both 500-kV lines are suddenly taken out of service. In such an event, the current in the Gates-Panoche double circuit (and also Gates-McCall and Gates-Gregg single circuit) 230-kV lines and in the Gates 500/230-kV transformer, which supplies power to this overhead line, must be limited to avoid violation of electrical line clearance minimums and damage from excessive winding temperature in the Gates autotransformers, respectively.

**Significance of Research** – As a result of this project, the real-time dynamic thermal rating of the Path15 transmission interface could be provided to the system operator to guide generation dispatch decisions during critical periods. In doing this, however, other limits on power flow through the Path15 interface need to be considered. These include, but are not limited to, the power flow limits on the series capacitors on the 500-kV lines and certain voltage and stability operation limits. Nonetheless, the anticipated result allows increased Path15 power flow under favorable conditions and limits Path15 power flow under unfavorable conditions so that major system components are not damaged in the event of the proposed contingency.

**Follow on (if appropriate)** – None.

#### **Project participants**

P. Hirsch, and A. Edris, EPRI

S. Sethu, Best Systems, Inc.

D. Douglass and T. Raymond, Power Delivery Consultants, Inc.

N. Reppen, Niskayuna Power Consultants, Inc.

T. Seppa, The Valley Group, Inc.

R. Ulrich, Ulrich Associates, Inc.

#### **Publications**

EPRI. *Development of Path 15 Software, Managing Power Transfer Constraints on a Major Transmission Interface: Path 15 of the California Transmission System with EPRI's DTCR Technology*. TR-1009280. 2003.





### **Task 2.3.15 Forward Markets Administration**

**Summary** – Aspects of a short-term electricity market simulator (STEMS) were designed, developed, tested and implemented on a small test system.

**Objectives** – To provide CA ISO with a tool to assist in the areas of: 1) Market design; 2) Operations studies and training; and 3) Market monitoring

**Leverage/partners/co-funding** – None.

**Approach** – This task was conducted in three phases. Phase 1 involved development of design documents for the forward market administrator and market participation modules. Phase 2 involved implementation and basic testing of the modules. Phase 3 involved integration and testing of the modules in STEMS using a small test system.

**Accomplishments** – Testing was completed using the PAL system, DSI-OPF, EPRI-Dynamics, and CIM.

**Significance of Research** – Market simulation tools can be a valuable aid in the design, operating, and mitigation of market of market power in competitive electricity markets. Market simulation can be used in assessing Day-Ahead and Intra-Day LMP markets, market power concerns, bidding strategies by Genco's and LSE's. The "market" results can be easily compared with classical "regulated" market results with flexibilities on modeling assumptions.

**Follow on (if appropriate)** – Tasks 2.3.16 and 2.3.17 were conducted as follow-on activities in this area. It is important to test the software on actual utility (or ISO/RTO) systems. Also, alternative market models may need to be implemented to make the system applicable to an even wider range of market designs (e.g. Inter-Zonal models)

#### **Project participants**

P. Hirsch, EPRI  
Atif Debs, DSI

#### **Publications**

A. Debs, C. Hansen, Y. C. Wu, P. Hirsch and L. Szot, *Bidding Strategies for Genco's in the Short-Term Electricity Market Simulator (STEMS)*. IASTED International Conference on Intelligent Systems & Control. Salzburg, Austria. June 25-27, 2003.

### **Task 2.3.16 STEMS: Real-Time Market Simulator**

**Summary** – Aspects of the re-design of CA ISO's market were examined with an agent-based simulation tool using a simplified representation of a power system.

**Objectives** – To provide CA ISO with a tool to assist in the areas of: 1) Market design; 2) Operations studies and training; and 3) Market monitoring.

**Leverage/partners/co-funding** – This task builds in work completed under Task 2.3.15.

**Approach** – Experiments were conducted using computer-based agents to simulate the impact of CA ISO's then proposed automatic mitigation procedure (AMP) and available capacity market on market behavior.

**Accomplishments** – The simulations show that the AMP is effective in reducing market clearing prices under situations when the would otherwise reach the price cap and that congestion rents can be fleeting when suppliers are able to equalize prices across zones through strategic bidding. The simulations also indicate that the proposed available capacity market of the CA ISO Market Design 2002 will result in heightened payments for capacity, because this market will not remove capacity payments from the energy market.

**Significance of Research** – The studies conducted in this task demonstrate that agent-based simulation is a useful tool for analyzing existing and proposed design features of electricity markets.

**Follow on (if appropriate)** – Task 2.3.17 was conducted as a follow-on to this task.

#### **Project participants**

R. Entriken, EPRI.

Hung-po Chao, EPRI

Steve Wan, EPRI

Robert Wilson, Stanford University

Peter Cramton, University of Maryland

Alex Papalexopoulos, ECCO International

#### **Publications**

EPRI. *Agent-Based Simulation of an Automatic Mitigation Procedure*. TR-1007733. 2003.

EPRI. *Pushing Capacity Payments Forward: Agent-Based Simulation of an Available Capacity Market*. TR-1007755. 2003.

### **Task 2.3.17 STEMS: Data Tools and User Interface**

**Summary** – Aspects of STEMS were incorporated into the EPRI OTS developed under Task 2.3.13.

**Objectives** – To provide CA ISO with a tool to assist in the areas of: 1) Market design; 2) Operations studies and training; and 3) Market monitoring by improving and making more flexible the Short Term Electricity Market Simulator.

**Leverage/partners/co-funding** – Some of the work is based on on-going work by EPRI and its members, such as Common Information Model (CIM), Application Programming Interface (API), CIM/XM importer and Operator Training Simulator (OTS)

**Approach** – This task involved integration of aspects of STEMS into the EPRI OTS previously developed in Task 2.3.13. The first phase involved delivery of the OTS with enhanced database tools. The second phase involved delivery of OTS with user interface enhancements.

**Accomplishments** – The CIM database tools were modified to integration of STEMS. Enhancements to facilitate identification of congestion and testing manual and optimized remedial actions were developed. The ultimate goals of this task were not completed because the CA ISO was not able to provide their real-time network model in time for incorporation into the task.

**Significance of Research** – Market simulation tools can be a valuable aid in the design, operating, and mitigation of market of market power in competitive electricity markets.

**Follow on (if appropriate)** – None.

#### **Project participants**

P. Hirsch and R. Entriken, EPRI  
A.Debs, Decision Systems International  
R. Podmore, Incremental Systems  
M. Robinson, PowerData Corporation.

**Publications** – None.

### **Task 2.3.18 Network Reliability Project**

**Summary** – This task studied how grid and service reliability were maintained in real time during California’s electricity crisis.

**Objectives** – To analyze California’s electricity restructuring and crisis from the perspective of grid and service reliability under persisting real-time performance conditions and to examine the continuing institutional design implications of the changing nature of electricity reliability in volatile markets.

**Leverage/partners/co-funding** – None.

**Approach** – Sixty interviews were conducted with CA ISO control room personnel and representatives of utilities, energy trading companies, and regulatory agencies, among others. Recommendations were made on developing reliability as a profession through improved training, communications, and public recognition.

**Accomplishments** – Deregulated markets make it much more difficult and expensive to coordinate interdependency among many market participants. The proportions of time spent between real-time operations and longer-term management, planning, and investment have permanently changed. Adjusting to the new real-time burden and balancing it with other strategies for grid management have become a permanent feature of the California power system.

Proposed improvements in the California electricity system should be examined to see if they will increase system volatility, decrease available options to balance load and generation in response to that volatility, or interfere with the adaptability of those responsible to maintain and ensure grid and service reliability. Improving reliability may depend more on fostering the professionalism and expertise of the people responsible for real-time operations than on any change in organizational design.

**Significance of Research** – Many policy proposals are currently being made to change the electricity system, but recognizing and supporting the professionals responsible for reliability management may be more important than particular design issues. The real story of the California electricity crisis is not about structures, but about the skills that matter under changing performance conditions in real time.

**Follow on (if appropriate)** – The project led to subsequent research and major recommendations to CA ISO’s new CEO and team.

#### **Project participants**

P. Hirsch, EPRI

E. Roe, Mills College

#### **Publications**

EPRI. *California’s Electricity Restructuring: The Challenge to Providing Service and Grid Reliability*. TR-1007388. 2002.

### **Task 2.9.5 Transfer Limit Application of Community Action Room to California ISO**

**Summary** – This project was discontinued following initial discussions with CA ISO.

**Objectives** – To calculate transfer limits within the WECC using the EPRI/ ABB TRACE program and display the results to CA ISO system operators using the EPRI Community Activity Room (CAR) software.

**Leverage/partners/co-funding** – N / A.

**Approach** – N / A.

**Accomplishments** – N / A.

**Significance of Research** – N / A.

**Follow on (if appropriate)** –

**Project participants**

P. Hirsch, and S. Lee, EPRI

**Publications** – None.

#### **4. Integration of Distributed Energy Resources Integration**

The objective of this area of research is to create the technologies and control strategies needed to capture the full potential of distributed energy resources (DER) to improve the reliability of the California interconnected power system. This includes consideration of control systems, including the sensors and instruments necessary to gather intelligence for real-time power management, and dispatch or coordination among distributed generation resources. It also includes improved modeling techniques to better characterize the technologies and their impacts on the distribution (and ultimately the transmission) system. With correct placement and control, it should be possible to increase system reliability, lower the cost of power delivery, improve power quality, and reduce the environmental impacts of producing and transmitting electricity.

CERTS research in this area is organized around the concept of a DER microgrid. A microgrid is an integrated power delivery system consisting of interconnected loads and distributed energy resources, which as an integrated system can operate in parallel with the grid or in an intentional island mode. The integrated DER are capable of providing sufficient and continuous energy to a significant portion of the internal load demand. The microgrid possesses independent controls and can island with minimal service disruption.

The focus of the research is to advance the CERTS Microgrid concept to commercialization. The immediate objectives addressed in this contract have been to develop the concept and conduct supporting research to the point at which a controlled laboratory test bed demonstration can be conducted using full-scale micro-sources. Following the test bed demonstration, a field demonstration is envisioned. Research in support of this objective was conducted under two tasks: Task 2.4 and Task 2.7. The final selection of a laboratory and conduct of the test bed demonstration is being conducted under a separate Energy Commission PIER contract with CERTS (#500-03-024).

Four tasks were completed under the original scope of Contract #150-99-003:

Task 2.4.1 Proof-of-Concept for Microgrid Control

Task 2.4.2 Standard Power Electronic Interface

Task 2.4.3 Distributed Energy Resources (DER) Customer Adoption Model (formerly, Effects of Ancillary Services Market Participation on Customer Distributed Energy Resources (DER) Adoption)

Task 2.4.4 Planning and Technical Support for California DER Test Beds

Five tasks were completed under Amendment A of Contract #150-99-003:

Task 2.7.1 Microgrid Control

Task 2.7.2 Microgrid Test Bed Design and RFP (continuation of Task 2.4.4)

Task 2.7.3 Field Demonstration Planning

Task 2.7.4 DER Customer Adoption Model (continuation of Task 2.4.3)

Task 2.7.5 DER Transfer/Closeout

Research activities were closely coordinated with related activities sponsored by the U.S. DOE Transmission Reliability program.

### **Task 2.4.1 Proof-of-Concept for Microgrid Control**

**Summary** – This task contributed to the first articulation of the CERTS Microgrid concept for integration of distributed energy resources.

**Objectives** – To describe an entirely new approach to integrating DER called the CERTS Microgrid. The concept assumes an aggregation of loads and microsources operating as a single system providing both power and heat. The majority of the microsources must be power electronic based to provide the required flexibility to insure operation as a single aggregated system. This control flexibility allows the microgrid to present itself to the bulk power system as a single controlled unit that meets local needs for reliability and security.

**Leverage/partners/co-funding** – The development of the CERTS Microgrid concept was also supported through co-funding to CERTS by the U.S. DOE Transmission Reliability program.

**Approach** – A white paper was prepared that identified and explored key technical issues raised by the CERTS Microgrid concept. Background and contextual information relevant to microgrids is presented, which briefly describe generation technologies implementable in microgrids and the particular role that combined heat and power could play in microgrids. Microgrid design and operation are then described in detail. Key technical challenges associated with the CERTS Microgrid are delineated, including: a) their presentation to the bulk power provider grid, b) controls required for them to function effectively both in connection to the bulk power provider grid and in isolation (or islanded) from the grid, and c) protection and safety issues that must be addressed. The white paper also discusses some fundamental economic questions that will ultimately dictate the configuration and operation of a microgrid. The white paper concludes by highlighting areas of needed research.

**Accomplishments** – Preparation of a white paper articulating the concept of and key technical issues addressed by the CERTS Microgrid.

**Significance of Research** – From the grid's perspective, the central advantage of a microgrid is that it can be regarded as a controlled entity within the power system that can be operated as a single aggregated load. Customers benefit from a microgrid because it is designed and operated to meet their local needs for heat and power as well as provide uninterruptible power, enhance local reliability, reduce feeder losses, and support local voltages/correct voltage sag.

**Follow on (if appropriate)** – A full-scale demonstration of the CERTS Microgrid concept at a utility laboratory test-bed is being conducted by CERTS under a separate follow on Energy Commission PIER contract (#500-03-024).



**Project participants**

Bob Lasseter, University of Wisconsin/PSERC

Abbas Akhil and John Stevens, Sandia National Laboratories

Chris Marnay and Joe Eto, Lawrence Berkeley National Laboratory

Sakis Meliopoulos, Georgia Tech/PSERC

Jeff Dagle and Ross Guttromson, Pacific Northwest National Laboratory

Bob Yinger, Southern California Edison

**Publications**

Lasseter, R., A. Akhil, C. Marnay, J. Stevens, J. Dagle, R. Guttromson, A. Meliopoulos, R. Yinger, J. Eto. *Integration of Distributed Energy Resources: The CERTS Microgrid Concept*. LBNL-50829. April 2002. P500-03-089F. October 2003.

[www.energy.ca.gov/pier/final\\_project\\_reports/500-03-089f.html](http://www.energy.ca.gov/pier/final_project_reports/500-03-089f.html)

R.H. Lasseter. *MicroGrids*. IEEE PES, New York, NY. 2002.

### Task 2.4.2 Standard Power Electronic Interface

**Summary** – This task prepared a scoping study and proof-of-concept hardware prototype for a state-of-the-art, standardized Integrated Power Electronics Modules (IPEMs) module concept for application to distributed generation.

**Objectives** – To contribute to the realization of a ten-fold reduction in the cost of power electronics with specific application to distributed generation in ten years.

**Leverage/partners/co-funding** – The task leveraged activities of the National Science Foundation (NSF)-sponsored Center for Power Electronics Systems (CPES) to design standardized Integrated Power Electronics Modules (IPEMs).

**Approach** – The focus was on the application of modular building blocks to realize low cost power electronic converters for use in distributed generation systems. The researchers developed a set of requirements to ensure that the general purpose power processing modules (developed originally with motor drive applications in mind) would have the flexibility required for applications to distributed generation. This was performed by studying the nature of loads in industrial distribution systems, protection issues, synchronization issues, control issues, active and reactive power sharing, etc. The investigations led to development of a modular architecture that would allow using pre-engineered and mass-produced components to develop power electronic solutions in a systematic manner. A hardware prototype was presented to demonstrate proof of concept and explore properties of the proposed approach. Technical and practical implementation issues were introduced and discussed. A concept design review meeting with a number of participants from the power electronics industry was held to disseminate the ideas and solicit inputs.

**Accomplishments** – The researchers developed a set of requirements to ensure that the general purpose power processing modules (developed with motor drive applications in mind) developed by CPES would have the flexibility required for application to distributed generation. A new framework for realization of power converter was developed called Bricks-&-Buses. This framework requires three elements: modular components or bricks, from which any practical converter topology can be constituted; buses, or connective architectures, for interconnection of the bricks; a software environment in which to describe the converter at an abstracted level and automatically generate engineering and design files.

**Significance of Research** – Power electronic converters represent a significant fraction of the cost of present day DER systems because, traditionally, design and manufacturing of power electronic systems has taken place on an application specific basis. This has resulted in product-specific designs with low volume and large overhead in development, engineering and tooling for manufacturing. The vision of NSF-sponsored Center for Power Electronics Systems (CPES) is focused on the development of an integrated systems approach to standardize power electronics components and packaging techniques in the form of highly Integrated Power Electronics Modules (IPEMs). The IPEM approach makes possible increased levels of integration in the components that comprise a power electronic system - devices, circuits, controls, sensors, and actuators. These components are integrated into standardized manufacturable subassemblies and modules, which, in turn, are customized for particular applications.

**Follow on (if appropriate)** – Both DOE and the Energy Commission are exploring options for establishing more formal programs of research on power electronics for distributed generation applications.

**Project participants**

Giri Venkataramanan, University of Wisconsin/PSERC.

**Publications**

Flannery, P., G. Venkataramanan, and B. Shi. 2004. *Integration of Distributed Technologies – Standard Power Electronic Interfaces*. P500-2005-119. April 2004.

[www.energy.ca.gov/pier/final\\_project\\_reports/CEC-500-2005-119.html](http://www.energy.ca.gov/pier/final_project_reports/CEC-500-2005-119.html)

Venkataramanan, G. *Integration of Distributed Technologies – Standard Power Electronic Interfaces*. September 2001.

**Task 2.4.3 Distributed Energy Resources (DER) Customer Adoption Model** (formerly, Effects of Ancillary Services Market Participation on Customer Distributed Energy Resources (DER) Adoption)

**Task 2.7.4 Distributed Energy Resources Customer Adoption Model**

**Summary** – This task enhanced the CERTS Distributed Energy Resources Customer Adoption Model (DER-CAM) to improve its ability to analyze real-time prices for real power and ancillary services, and combined heat and power systems.

**Objectives** – To develop an analysis tool that minimizes the cost of supplying electricity to a specific customer by optimizing the installation of distributed generation and the self-generation of part or all of its electricity.

**Leverage/partners/co-funding** – The U.S. DOE Transmission Reliability program provided initial support to CERTS for the development of DER-CAM. The U.S. DOE Distributed Energy Resources program has provided additional funding for benchmarking and validation of DER-CAM.

**Approach** – DER-CAM is an economic model of customer DER adoption implemented in the General Algebraic Modeling System (GAMS) optimization software. The model is used to find the cost-minimizing combination of on-site generation technologies, given prevailing economic conditions, and customer energy requirements. The key inputs to the model are the customer's load profile; the capital, operation and maintenance (O&M), and fuel costs of the various available DER technologies; and the cost of electricity (under various tariff options, including real-time prices from the CA ISO) and the cost of fuel. With these inputs, the model determines:

- The optimal, cost-minimizing capacity of each technology to be installed;
- When and how much of the installed capacity will be running; and
- The total cost of supplying electricity.

**Accomplishments** – The key accomplishments of the work were the acquisition of increasingly accurate data on DER technologies, including the development of methods for forecasting cost reductions for these technologies, and the creation of a credible example California microgrid test case for use in this study and in future work. In addition, combined heat and power (CHP) technologies were incorporated. Finally, based on the insights gained through developing DER-CAM, the Site Energy Supply and Use Model was developed to provide a simulation platform for examining energy manager strategies for a microgrid.

**Significance of Research** – The addition of CHP to DER-CAM is a major step towards creating a realistic customer adoption model. As is seen in industry and confirmed in results in this report, the recovered waste heat from DER is of significant value and often tips the scales in favor of DER over macrogrid dependence.

**Follow on (if appropriate)** – The U.S. DOE Distributed Energy Resources program is sponsoring enhancements and project analyses using the model.

**Project participants**

Chris Marnay, Lawrence Berkeley National Laboratory

**Publications**

Marnay, C., J. Chard, K. Hamachi, T. Lipman, M. Moezzi, B. Ouaglal, and A. Siddiqui. 2001. *Modeling of Customer Adoption of Distributed Energy Resources*. LBNL-49582. August 2001. P500-03-094F. October 2003. [www.energy.ca.gov/pier/final\\_project\\_reports/500-03-094f.html](http://www.energy.ca.gov/pier/final_project_reports/500-03-094f.html)

Siddiqui, A., R. Firestone, S. Ghosh, M. Stadler, J. Edwards and C. Marnay. *Distributed Energy Resources Customer Adoption Modeling with Combined Heat and Power Applications*. LBNL-52718. June 2003. P500-04-007. February 2004. [www.energy.ca.gov/pier/final\\_project\\_reports/500-04-007.html](http://www.energy.ca.gov/pier/final_project_reports/500-04-007.html)

#### **Task 2.4.4 Planning and Technical Support for California DER Test Beds**

#### **Task 2.7.2 Microgrid Test Bed Design and RFP**

**Summary** – This task created a preliminary design for a full-scale laboratory test bed for demonstration of CERTS Microgrid concepts. It also established criteria for selection of a utility-host for the laboratory test bed and evaluated qualifications of potential sites.

**Objectives** – To design a full-scale laboratory test bed for demonstration of CERTS Microgrid concepts and to make a recommendation for selection of a utility RD&D laboratory to host the test bed.

**Leverage/partners/co-funding** – Several of the preparatory activities were co-funded by the U.S. DOE Transmission Reliability program.

**Approach** – Preparatory work consisted of the following four activities: 1) A survey assessing available test facilities to conduct the test bed demonstration. 2) An assessment of commercially available energy management systems for suitability for use in the test bed demonstration. 3) Evaluation of dispatch algorithms for a DER for use by an energy management system that could operate a CERTS Microgrid. 4) Laboratory tests of individual microsource performance and of two microsources operating in parallel with one another.

Northern Power Systems (NPS) was retained by CERTS to prepare a preliminary laboratory test bed design. The final test bed design will be developed by NPS in conjunction with the utility selected to host the laboratory test bed under the follow-on Energy Commission PIER contract (#500-03-024).

Selection criteria for the laboratory test bed were developed. Following discussion and approval from the Energy Commission PIER, it was decided that site selection would not be conducted through an RFP process due to the uniqueness of the test bed requirements. A critical requirement is significant corporate support for the project and involvement of relevant distribution engineering expertise in the design and conduct of the tests.

Based on preparatory work identifying potential utility partners for the tests described above, statements of qualifications were sought from three utilities. Interviews were conducted with and, following this, site visits were held with two of the utilities.

**Accomplishments** – Five technical reports were prepared summarizing each element of the preparatory work. A preliminary test bed design was prepared and revised based on input from the Technical Advisory Committee. A recommendation was made to the Energy Commission PIER for selection of American Electric Power as the utility partner for the laboratory test bed demonstration.

**Significance of Research** – There has never been a full-scale demonstration of the CERTS Microgrid concept. Development of a test bed design and selection of a utility partner to conduct this demonstration is a critical step toward commercialization.

**Follow on (if appropriate)** – The full-scale demonstration of the CERTS Microgrid concept at the selected utility laboratory test bed is being conducted by CERTS under a separate, follow on Energy Commission PIER contract (#500-03-024).

### **Project participants**

John Stevens, Sandia National Laboratories  
Bob Lasseter, University of Wisconsin/PSERC  
Chris Marnay and Joe Éto, Lawrence Berkeley National Laboratory  
John Kueck, Oak Ridge National Laboratory  
Bob Yinger, Southern California Edison  
Ed Linton, Northern Power Systems

### **Publications**

Yinger, R. 2001. *Behavior of Capstone and Honeywell Microturbine Generators during Load Changes*. LBNL-49095. July 2001. P500-04-021. February 2004.  
[www.energy.ca.gov/pier/final\\_project\\_reports/500-04-021.html](http://www.energy.ca.gov/pier/final_project_reports/500-04-021.html)

Akhil, A., C. Marnay, T. Lipman. *Review of Test Facilities for Distributed Energy Resources*. SAND2003-1602. October 2002. LBNL-51954. October 2002. P500-03-090F. October 2003.  
[www.energy.ca.gov/pier/final\\_project\\_reports/500-03-090f.html](http://www.energy.ca.gov/pier/final_project_reports/500-03-090f.html)

Kueck, J.D., R.H. Staunton, S.D. Labinov, B.J. Kirby. 2003. *Microgrid Energy Management System*. ORNL/TM-2002/242. January 2003. P500-03-091F. October 2003.  
[www.energy.ca.gov/pier/final\\_project\\_reports/500-03-091f.html](http://www.energy.ca.gov/pier/final_project_reports/500-03-091f.html)

Yinger, R. *Behavior of Two Capstone 30kW Microturbines Operating in Parallel with Impedance Between Them*. LBNL-55907. July 2004. CEC500-2005-052. March 2005.  
[www.energy.ca.gov/pier/final\\_project\\_reports/CEC-500-2005-052.html](http://www.energy.ca.gov/pier/final_project_reports/CEC-500-2005-052.html)

Firestone, R., and C. Marnay. 2005. *Energy Manager Design for Microgrids*. LBNL-54447. January 2005. CEC500-2005-051. March 2005.  
[www.energy.ca.gov/pier/final\\_project\\_reports/CEC-500-2005-051.html](http://www.energy.ca.gov/pier/final_project_reports/CEC-500-2005-051.html)

Marnay, C., and O.C. Bailey. 2004. *The CERTS Microgrid and the Future of the Macrogrid*. August 2004. <http://eetd.lbl.gov/EA/EMP/reports/55281.pdf>

### **Task 2.7.1 Microgrid Control**

**Summary** – This task developed a proof of concept simulation and bench-scale emulation of the CERTS Microgrid including appropriate implementation of control functions and integration of distributed storage (on the DC bus of the microsources) with the system.

**Objectives** – To identify and begin to examine the CERTS Microgrid control issues that will later be tested by a physical test bed.

**Leverage/partners/co-funding** – None.

**Approach** – Both simulation and bench-scale testing of CERTS Microgrid concepts was undertaken. Simulations were conducted using the Electromagnetic Transients Program (EMTP) software program, which is the industry standard analysis tool for studying sub-cycle electrical phenomena. Bench-scale testing was conducted using an emulation of the CERTS Microgrid with 3 DC power sources operated at 15kW. (The full-scale tests will involve three microsources operating at 60kW each.) Testing was conducted in grid-connected and islanded modes of operation and especially in situations where operation switched rapidly from the grid-connected to the islanded mode of operation.

**Accomplishments** – The simulations and bench-scale emulations demonstrated the ability of the CERTS Microgrid to control voltage and frequency, and share loads rapidly when operated in an islanded mode as well as through the transition from the grid-connected to the islanded mode of operation.

**Significance of Research** – Inverter-based DER devices are fundamentally different from conventional central station generation technologies. For instance, fuel cells and battery storage devices have no moving parts and microturbines have extremely lightweight moving parts. The dynamic performance of these “inertia-less” devices cannot be modeled simply as if they were scaled down central station units. Current power systems have storage in generators’ inertia. When a new load comes on line the initial energy balance is satisfied by the system’s inertia. This results in a slight reduction in system frequency. A system with clusters of micro-generators must operate in an island mode to provide some form of storage to the initial energy balance as “virtual inertia”. The control of the inverter without a complex communication system to provide this functionality is key to the successful performance of the CERTS Microgrid.

**Follow on (if appropriate)** – The algorithms developed and tested in simulation and through bench-scale emulation will be incorporated into the inverters developed for the full-scale test of the CERTS Microgrid concept.

#### **Project participants**

Bob Lasseter, University of Wisconsin/PSERC



**Publications**

Lasseter, R.H., P. Piagi. *Microgrid: A Conceptual Solution*. PSEC '04, Aachen, Germany. June 20-25, 2004.

## **Task 2.7.2 Microgrid Test Bed Design and RFP**

**Summary** – See Task 2.4.4

### **Task 2.7.3 Field Demonstration Planning**

**Summary** – This task evaluated options conducting a field demonstration of the CERTS Microgrid Concept.

**Objectives** – To establish a process for selection of a field demonstration partner for the CERTS Microgrid concept.

**Leverage/partners/co-funding** – None.

**Approach** – CERTS team members made presentations on the CERTS Microgrid concept in a variety of forums, including meetings of CADER and IEEE, as well as at professional meetings hosted by the Energy Commission and DOE. CERTS team members also discussed possibilities for field demonstrations with individual DER sites, Technical Advisory Committee (TAC) members, and with partners for the laboratory test bed demonstrations.

**Accomplishments** – The CERTS team and the Energy Commission have determined through that the most likely candidates for a field demonstration will be identified and sponsored by the utilities participating on the TAC for the project, or by the industry partners involved in the laboratory test bed demonstration, such as the manufacturer of the primemover that will be used in the test bed demonstration.

**Significance of Research** – A field demonstration of the CERTS Microgrid Concept is the next step, following the laboratory test bed demonstration, and the final step prior to commercialization.

**Follow on (if appropriate)** – Potential hosts for a field demonstration are under discussion with the TAC for the project as well as with the partners for the full-scale demonstration of the CERTS Microgrid Concept.

#### **Project participants**

Chris Marnay, Lawrence Berkeley National Laboratory  
John Stevens, Sandia National Laboratories  
Bob Lasseter, University of Wisconsin/P SERC

**Publications** – None.

## **Task 2.7.4 Distributed Energy Resources Customer Adoption Model**

**Summary** – See Task 2.4.3

#### **Task 2.7.5 DER Transfer/Closeout**

**Summary** – This task was completed because the Energy Commission PIER determined that it was no longer needed since the project was moving onto follow-on Energy Commission PIER contract (#500-03-024).

**Objectives** – This task provided an option for the Energy Commission PIER to close-out the development of a laboratory test bed demonstration of the CERTS Microgrid concept in the event that technical barriers prevented moving to the laboratory test bed phase of this research.

**Leverage/partners/co-funding** – N/A

**Approach** – N/A

**Accomplishments** – The project is successfully moving into the laboratory test bed phase and therefore this specific task is no longer needed.

**Significance of Research** – N/A

**Follow on (if appropriate)** – The full-scale demonstration of the CERTS Microgrid concept at the selected utility laboratory test bed is being conducted by CERTS under a separate, follow on Energy Commission PIER contract (#500-03-024).

**Project participants** – N/A

**Publications** – N/A

## **5. Reliability and Markets**

The objective of this area of research is to ensure that a fair and transparent market for electricity and ancillary services will provide reliable energy efficiently to California energy consumers. The reliable operation of power systems depends critically on the availability of sufficient quantities of various reliability-related (or ancillary) services to the system operator. The ancillary service requirements of the California interconnected power system are based on the need to ensure compliance with NERC and WSCC requirements. As witnessed by the extraordinary market problems experienced by California during 2000 and 2001, achieving the appropriate balance between ideal economic market mechanisms and traditional utility operating practices is difficult.

CERTS research in this area is interdisciplinary, requiring expertise from the disciplines of both power system engineering and market economics. A major thrust of the research is focused on increasing the role of demand in contributing to the health and improved functioning of markets. This led, through the contract amendment, to creation of an entire area of research (Task 2.8) devoted to the concept of load as a resource or demand response.

Three tasks were completed under the original scope of Contract #150-99-003:

Task 2.5.1 Utilization of Load as a Bulk-System Imbalance Energy and Ancillary Service Resource

Task 2.5.2 Comparing Alternative Approaches to Congestion Management (formerly, Identifying Ancillary Service Reserve Requirements vs. Total Generation/Load)

Task 2.5.3 CA ISO's Congestion Management Philosophy and Design

Research activities were closely coordinated with related activities sponsored by the U.S. DOE Transmission Reliability program.

### **Task 2.5.1 Utilization of Load as a Bulk-System Imbalance Energy and Ancillary Service Resource**

**Summary** – This task initiated a program of research and demonstration to increase load participation in wholesale electricity markets.

**Objectives** – To identify the technical requirements for loads to participate in the ancillary services and real-time energy markets and to initiate efforts to further research and demonstrate this concept.

**Leverage/partners/co-funding** – This activity was co-funded by the U.S. DOE Transmission Reliability program.

**Approach** – Four sub-tasks were conducted: First, a scoping study was prepared that: a) examined the inherent capability of various load types to potentially provide reliability services to the power system; b) reviewed existing utility load management programs; c) reviewed recent developments in communications and control technologies to support load participation in electricity markets; and d) began outlining an RD&D agenda on this topic. Second, demonstration planning was undertaken, starting with a supermarket chain. Third, a detailed review of Southern California Edison's existing load management assets from the standpoint of requirements to migrate the use of these assets to provision of ancillary services was prepared. Fourth, experimental economic modeling capabilities, developed previously, were modified to accommodate load participation in energy and ancillary service markets.

**Accomplishments** – Technical reports or letter reports were prepared on the findings from each sub-task. The Energy Commission PIER ESI program subsequently established a program on Demand Response to continue and expand upon work on this topic. CERTS was tasked to administer three initial tasks in this new program, which were supported under an amendment to Contract #150-99-003; these tasks are described under Task 2.8.

**Significance of Research** – The research conducted in this task has contributed to greater awareness and appreciation for the importance of providing for load participation in wholesale electricity markets. CERTS-led demonstrations of load as a resource are in various stages of development both in California and in other parts of the country.

**Follow on (if appropriate)** – As noted, the Energy Commission PIER ESI created a Demand Response program that has supported follow-on research by CERTS in this program area.

#### **Project participants**

Brendan Kirby and John Kueck, Oak Ridge National Laboratory

Tim Mount, Cornell University/PSEER

Carlos Martinez, Southern California Edison

Joe Eto, Chuck Goldman, and Chris Marnay, Lawrence Berkeley National Laboratory

#### **Publications**

Weller, G.H. *Review of Current Southern California Edison Load Management Programs and Proposal for a New Market-Driven, Mass-Market, Demand-Response Program*. LBNL-52866. January 2002. P500-04-022. February 2004.

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Kirby, B. J. Kueck. *Spinning Reserve from Pump Load: A Technical Findings Report to the California Department of Water Resources*. ORNL/TM-2003/99. November 2003. P500-04-006. February 2004. [www.energy.ca.gov/pier/final\\_project\\_reports/500-04-006.html](http://www.energy.ca.gov/pier/final_project_reports/500-04-006.html)

Kueck, J., B. Kirby, J. Eto, R. Staunton, C. Marnay, C. Martinez, C. Goldman. *Load as a Resource in Restructured Electricity Markets*. ORNL/TM2001/97. June 2001. LBNL-47983. June 2001. P500-03-092F. October 2003. [www.energy.ca.gov/pier/final\\_project\\_reports/500-03-092f.html](http://www.energy.ca.gov/pier/final_project_reports/500-03-092f.html)

Mount, T., S. Yoo. *Designing Forward Markets for Electricity to Meet the Needs of Customers*. 21<sup>st</sup> Annual Western Conference. Advanced Workshop in Regulation and Competition, Competitive Change in Network Industries. Newport, Rhode Island. May 22-24, 2002.

Mount, T. *Using Weather Derivatives to Improve the Efficiency of Forward Markets for Electricity*. 35th Hawaii International Conference on System Sciences. Big Island, Hawaii, USA. January 2002.



**Task 2.5.2 Comparing Alternative Approaches to Congestion Management** (formerly, Identifying Ancillary Service Reserve Requirements vs. Total Generation/Load)

**Summary** – This task was re-scoped to prepare a review of emerging congestion management approaches and to develop a framework for assessing their performance.

**Objectives** – To develop metrics that could be used to evaluate and compare the performance of different approaches in use by ISOs for congestion management.

**Leverage/partners/co-funding** – None.

**Approach** – The report first presents an overview and background on key issues and emerging approaches to congestion management. It goes on to identify and describe policies affecting congestion management that are favored and/or are now being considered by FERC, NERC, and one of the regional reliability councils (WSCC). It reviews the operational procedures in use or proposed by three of the leading independent system operators (ISOs) including ERCOT, California ISO, and PJM. Finally, it presents recommendations for evaluating the competing alternative approaches and developing metrics to use in these evaluations.

**Accomplishments** – Articulation of considerations that must be taken into account in developing metrics that can be used to evaluate and compare the performance of different approaches in use by ISOs for congestion management.

**Significance of Research** – Transmission congestion occurs when there is insufficient transmission capacity to simultaneously accommodate all requests for transmission service within a region. Congestion management schemes used today have negative impacts on energy markets, such as disruptions and monetary penalties, under some conditions. To mitigate these concerns various congestion management methods have been proposed, including redispatch and curtailment of scheduled energy transmission. While there are many metrics in use for measuring congestion, there are no accepted methods for evaluating the performance of congestion management systems. This task contributes to improving our ability to compare and contrast these methods on a consistent basis.

**Follow on (if appropriate)** – None.

**Project participants**

Brendan Kirby, Oak Ridge National Laboratory  
Carlos Martinez, Electric Power Group

**Publications**

Kirby, B.J., J.W. Van Dyke, C. Martinez and A. Rodriguez. *Congestion Management Requirements, Methods and Performance Indices*. ORNL/TM-2002/119. June 2002. P500-2005-166. November 2005. [www.energy.ca.gov/pier/final\\_project\\_reports/CEC-500-2005-166.html](http://www.energy.ca.gov/pier/final_project_reports/CEC-500-2005-166.html)

### **Task 2.5.3 CA ISO's Congestion Management Philosophy and Design**

**Summary** – This task investigated existing and alternative mechanisms and methodologies for creating new zones for use by CA ISO in managing congestion.

**Objectives** – To investigate methodologies for re-specification of electrical/geographic zones that would be suitable for use as the basis for revisions to CA ISO's market-based approach to managing congestion through zonal pricing.

**Leverage/partners/co-funding** – This study was a complement to and coordinated with a parallel study sponsored by the CA ISO.

**Approach** – The report starts with a review of congestion concepts, then proceeds with a review of nodal and zonal pricing. It then reviews the CA ISO's own criteria for zone partitioning. It then evaluates the notion of "nodal price patterns." Finally, using the notion of nodal price pattern, it defines a methodology for zone creation and partitioning and finally demonstrates its use by means of an example.

**Accomplishments** – It is shown that, although nodal prices and zonal prices depend on the cost of generation, the price *patterns* associated with zonal and nodal prices are largely a function of the network and do not depend on the prices at the various generators. Thus, it is possible for the most part to separate the concept of zone partitioning from the cost and location of individual generators.

**Significance of Research** – It is recognized that in meshed networks, zones are only approximations to individual node pricing. The objective, however, is to create zones that closely approximate the "correct" nodal prices under most conditions and where the majority of the "commercially significant" value of the locational pricing is captured. In its October 30, 1997 Order, FERC directed the CA ISO to undertake a study to, among other directives, evaluate the effectiveness of its 5% criterion and calculate the congestion costs associated with currently inactive inter-zonal interfaces. This task contributed to CA ISO's study.

**Follow on (if appropriate)** – None.

#### **Project participants**

Fernando Alvarado, University of Wisconsin/PSERC

#### **Publications**

Alvarado, F.L. and W. Liu. *Methodology for Automatic Zone Creation/Merging/Partitioning*. P500-03-093F. October 2003. [www.energy.ca.gov/pier/final\\_project\\_reports/500-03-093f.html](http://www.energy.ca.gov/pier/final_project_reports/500-03-093f.html)

## **6. Demand Response (Load as a Reliability Resource)**

The objective of this area of research is to develop new information to answer the following two questions:

- What can the State do to help build a real-time energy information, signaling, and response infrastructure that is flexible and simple enough so that it can address the next energy crises not only the last one?
- What are the most effective strategies (technology, tariffs, etc.) related to deploying a real-time demand responsiveness system that are cost-effective, require minimal end-user interaction yet are effective?

CERTS research in this area is a follow-on to the activities conducted under Task 2.5 but focused specifically on three demand-response (DR) areas directly related to California's electricity market: a) Determine the current status of California's DR capabilities for typical large commercial, semi-industrial and institutional (LCI&I) facilities; b) Assess customer response to tariffs and assess strategies to increase customer DR response; and c) Help determine what technology and systems are required by CA ISO so that it can manage a real-time, two-way signaling system.

Four tasks were completed under the amendment to Contract #150-99-003:

Task 2.8.1 Demonstrations and Case Studies for Large Commercial, Semi-Industrial and Institutional Buildings

Task 2.8.2 Customer Response to Day-Ahead Wholesale Market Prices: Case Study of RTP Program Experience in New York

Task 2.8.3 Developing a Research Agenda to Address the Utilization of Responsive Load as a Bulk Power System Reliability Resource

Task 2.8.4 Demand Response Demonstration

Research along this general line has been continued with the addition of new tasks through separate, follow-on Energy Commission PIER contracts with CERTS (#500-05-001), and with LBNL's Demand Response Research Center (#500-03-026), which are managed by the PIER Demand Response Program.

### **Task 2.8.1 Demonstrations and Case Studies for Large Commercial, Semi-Industrial and Institutional Buildings**

**Summary** – This task developed and evaluated the performance of new Automated Demand Response (Auto-DR) hardware and software technology in large facilities.

**Objectives** – To evaluate the technological performance of automated demand-response hardware and software systems in large commercial, semi-industrial and institutional buildings.

**Leverage/partners/co-funding** – Participants volunteered their facilities in order to conduct this research, which required significant in-kind engineering and facilities staff support.

**Approach** – A two-week test of fully automated DR was conducted at six facilities. The test consisted of providing a single fictitious continuous electric price signal to each facility. Depending on the price, which was elevated to two levels corresponding to a hypothetical critical-peak pricing program, each facility automatically implemented one of two demand response strategies that had been developed in advance of the tests. Researchers recruited the participating facilities, assisted in the development of their strategies, implemented the price server for use in the tests, conducted the tests, and analyzed the results.

**Accomplishments** – The major findings of the research were: 1) Fully automated DR is technically feasible with minor enhancements to current state-of-the-art technology; 2) New Internet technology enhances the capabilities of existing building systems to enable demand response; 3) Automation enhances demand response programs; 4) Large facilities support the objectives of DR; and 5) New knowledge is needed to procure and operate technology and strategies for DR.

**Significance of Research** – This task contributed to defining the amount of DR that might be available from LCI&I facilities – relying on already in-place technologies and control strategies - during the next electricity crisis.

**Follow on (if appropriate)** – The results of this task are being used to shape future PIER research on DR systems and enabling technologies to improve building controls. This research is being conducted through the LBNL Demand Response Research Center under PIER contract # 500-03-026.

#### **Project participants**

Mary Ann Piette, Lawrence Berkeley National Laboratory  
Christine Shockman, Shockman Associates

#### **Publications**

Piette, M. A., O. Sezgen, D. Watson, N. Motegi, C. Shockman, L. ten Hope. *Development and Evaluation of Fully Automated Demand Response in Large Facilities*. CEC-500-2005-013. January 2005. [www.energy.ca.gov/pier/final\\_project\\_reports/CEC-500-2005-013.html](http://www.energy.ca.gov/pier/final_project_reports/CEC-500-2005-013.html)

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### **Task 2.8.2 Customer Response to Day-Ahead Wholesale Market Prices: Case Study of RTP Program Experience in New York**

**Summary** – This task prepared an in-depth case study of 149 large commercial and industrial customer accounts that participated in Niagara Mohawk Power Company's (NMPC) real-time pricing program.

**Objectives** – To: 1) Characterize customer response to and satisfaction with real time pricing (RTP) based on day-ahead wholesale market prices in a retail competition environment; 2) Quantify price responsiveness of various groups of customers; 3) Characterize drivers to customers' hedging decisions and supply choices; and 4) Differentiate between customer response to SC-3A prices (RTP) and to NYISO DR program incentives.

**Leverage/partners/co-funding** – NMPC was an active and essential partner, providing customer load, price and account data, contributing to the study design, and supplying substantial in-kind support by encouraging customers to participate in the study. NYISO, the New York State Energy Research Authority, and the New York Public Service Commission also provided valuable assistance to the design and execution of this study.

**Approach** – A self-administered customer survey and follow-up telephone interviews with a subset of survey respondents were undertaken to provide primary data. Additionally, NMPC provided basic customer characteristics, customers' hourly billing data and commodity prices over 3-4 years. Price responsiveness of customers was assessed qualitatively through survey questions that probed customers' perceived response capability, and quantitatively through the estimation of price elasticity using demand models.

**Accomplishments** – Key findings from the study include: 1) Customers are generally satisfied with RTP as the default tariff, despite the views expressed by some that hedging options are not attractively priced relative to perceived risks; 2) Price response is modest overall but individual customer response is extremely variable; 3) ISO-DR programs complement RTP, providing measurable increases in DR when events are called, particularly for industrial customers. 4) Adoption of DR-enabling technology among SC-3A customers is modest.

**Significance of Research** – There is little information in the public domain to characterize and quantify how customers actually respond to alternative dynamic pricing schemes. The NMPC experience: 1) Shows that large customers are likely to provide a moderate amount of demand response when RTP is their default service tariff, even if some customers hedge against price volatility. However, subjecting customers to wholesale market variability is not sufficient to realize their full demand response potential. 2) Challenges conventional wisdom by indicating that the ability and inclination of customers to respond varies widely. 3) Indicates that there is a gap between what customers consider to be a fair hedge cost and what the market offers. 4) Shows that enabling technologies are not a necessary condition for price response. However, over the long term, without automated response, the amount of load shifted or foregone is likely to be limited and is probably not sustainable.

**Follow on (if appropriate)** – The results of this task are being used to shape future PIER research on DR policies, programs, and tariffs. This research is being conducted through the LBNL Demand Response Research Center under follow on contract # 500-03-026.

**Project participants**

Chuck Goldman, Lawrence Berkeley National Laboratory  
Bernie Neenan, Neenan Associates

**Publications**

Goldman, C., N. Hopper, O. Sezgen, M. Moezzi, R. Bharvirkar, B. Neenan, R. Boisvert, P. Cappers, D. Pratt. *Customer Response to Day-ahead Wholesale Market Electricity Prices: Case Study of RTP Program Experience in New York*. LBNL-54761. June 2004.

[http://eetd.lbl.gov/EA/EMP/reports/NMPC\\_LBNL\\_54761.pdf](http://eetd.lbl.gov/EA/EMP/reports/NMPC_LBNL_54761.pdf).

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### **Task 2.8.3 Developing a Research Agenda to Address the Utilization of Responsive Load as a Bulk Power System Reliability Resource**

**Summary** – This task developed a research agenda for expanding utilization of demand response by the CA ISO.

**Objectives** – To work with CA ISO to develop a research agenda to identify how responsive loads could increase power system reliability and adequacy, what behaviors are desirable, and what reliability services (ancillary services) responsive loads could provide.

**Leverage/partners/co-funding** – CA ISO staff participated actively in the project through interviews and review meetings.

**Approach** – The primary goal in the development of this research agenda for demand response is to accurately reflect the concerns and needs of the CA ISO. To accomplish this, two brainstorming meetings were held at the CA ISO offices in Folsom, California, and a series of telephone interviews were conducted with CA ISO staff. The results from the initial brainstorming meeting were grouped into the following four issues: 1) Program ease of use; 2) Using load to mitigate market fluctuations (demand elasticity) as well as for contingency response (reliability services); 3) Location and time issues with demand response; and 4) Pricing mechanisms and market. A “talking points” paper was sent to CA ISO staff explaining these results and telephone interviews were arranged to further define the needs and to discuss the problems as seen by the individual staff members.

**Accomplishments** – Five recurring themes emerged that form the basis for the requirements that future RD&D in this area must address: 1) Though there has been relatively little success with demand response programs to date, ISO personnel believe that responsive load has the *potential* to be a significant resource to increase reliability and mitigate price volatility; 2) Demand response must be location-specific to have real value; 3) Demand response programs must not increase the CA ISO work load; 4) Demand response programs must not degrade the CA ISO’s ability to forecast load. The response itself must be simple and certain; and 5) For a response program to be accepted, the benefits for the individual and the power system must be clear to customers, system operators, and regulators.

**Significance of Research** – Responsive load appears to be a greatly underutilized resource for addressing power system adequacy and reliability. Institutional, economic, and technical reasons have been proposed for this failure. This is especially important in a region with transmission and generation constraints. This research contributes to improving understanding of why responsive loads are minimally being utilized and what institutional, economic, and technical barriers exist.

**Follow on (if appropriate)** – Task 2.8.4 was developed and initiated to address the requirements identified in this task.

#### **Project participants**

Brendan Kirby and John Kueck, Oak Ridge National Laboratory



**Publications**

Kirby, B. and J. Kueck. *Demand Response Research Plan to Reflect the Needs of the California Independent System Operator*. ORNL/TM-2004/2. January 2004. P500-04-023. February 2004. [www.energy.ca.gov/pier/final\\_project\\_reports/500-04-023.html](http://www.energy.ca.gov/pier/final_project_reports/500-04-023.html)

#### **Task 2.8.4 Demand Response Demonstration**

**Summary** – This task developed a test plan for the first-ever large-scale demonstration of use of air-conditioning load curtailments to provide spinning reserve.

**Objectives** – To the use of load for provision of spinning reserve, initially, by undertaking demonstrations that will lead to changes in reliability rules promulgated by the Western Electric Coordinating Council (WECC), which currently prohibit use of load to provide this ancillary service.

**Leverage/partners/co-funding** – Southern California Edison (SCE) sponsored the installation of the load control devices used in the demonstration.

**Approach** – This task was developed based on the requirements identified in Task 2.8.3. At the on-set, a TAC, involving CA ISO operations staff, and representatives from relevant WECC Committees and all three IOUs, was formed to review and provide guidance on all aspects of the research.

The demonstration plan calls for deployment of a statistically significant number of end-use load control devices within a single SCE feeder. Short (20 min) curtailments will be scheduled once per weekday afternoon throughout an entire summer season. During the curtailments, the feeder loads will be telemetered in real time and made visible via a web-based platform to CA ISO staff, the TAC, among others. Precise time-stamping will measure the latencies at each step in the curtailment process. Time-stamped feeder data, supplemented by spot metering on a sample of devices, will be analyzed to develop statistically robust models of the time-evolution and magnitude of load curtailments.

**Accomplishments** – The demand response demonstration test plan was developed and vetted with the Technical Advisory Committee.

**Significance of Research** – Responsive load appears to be a greatly underutilized resource for addressing power system adequacy and reliability. This research addresses all five of the themes identified in Task 2.8.3, which currently impede greater utilization of this resource.

**Follow on (if appropriate)** – The demonstration outlined in the test plan is being conducted under a separate PIER contract #500-05-001.

#### **Project participants**

John Kueck and Brendan Kirby, Oak Ridge National Laboratory  
Bob Yinger, Mark Martinez, Carlos Torres, Southern California Edison  
Roger Wright, RLW Analytics  
Arup Barat, Connected Energy Corporation  
Joe Eto and Dave Watson, Lawrence Berkeley National Laboratory

**Publications**

CERTS. *Plan for Summer 2005 Demand Response Test on Southern California Edison Distribution Circuit*. 2005.

A complete technical report on the demonstration will be prepared as part of a separate Energy Commission PIER contract with CERTS (#500-05-001).

## 7. Glossary

ACEEE	American Council for an Energy-Efficient Economy
AGC	Automatic Generator Control
AMP	Automatic Mitigation Procedure
ANNSTLF	Artificial Neural Network Short-Term Load Forecaster
API	Application Program Interface
Auto-DR	Automated Demand Response
BPA	Bonneville Power Administration
CA ISO	California Independent System Operators
CADER	California Alliance For Distributed Energy Resources
CAR	Community Activity Room
CERTS	Consortium for Electric Reliability Technology Solutions
CHP	Combined Heat and Power
CIM	Common Information Model
DER	Distributed Energy Resources
DER-CAM	Distributed Energy Resources Customer Adoption Model
DOE	Department of Energy
DSI	Decision Systems, Inc.
EHV	Extra High-Voltage
EMTP	Electromagnetic Transients Program
EPG	Electric Power Group
EPRI	Electric Power Research Institute
ERCOT	Electric Reliability Council of Texas, Inc.
ESI	Energy Systems Integration
FERC	Federal Energy Regulatory Commission
FRCC	Florida Reliability Coordinating Council
GAMS	General Algebraic Modeling System
IASTED	International Association of Science and Technology for Development
IEEE	Institute of Electrical and Electronics Engineers, Inc
IMO	Independent Market Operators
IOU	Investor Owned Utility
IPEMs	Integrated Power Electronics Modules
ISOs	Independent System Operators
LCI&I	Large Commercial, Semi-industrial and Institutional
MISO	Midwest Independent System Operator
NERC	North American Electric Reliability Council
NMPC	Niagara Mohawk Power Company
NSF	National Science Foundation
NYISO	New York Independent System Operator
O&M	operation and maintenance
ORNL	Oak Ridge National Laboratory
OTS	Operator Training Simulator
PG&E	Pacific Gas & Electric
PIER	Public Interest Energy Research
PJM	Pennsylvania New Jersey Maryland
PNNL	Pacific Northwest National Laboratory
PSERC	Power Systems Engineering Research Center
PX	California Power Exchange
R&D	Research and Development

RD&D	Research, Development and Demonstration
RFP	Request for Proposal
RTP	Real Time Pricing
SCE	Southern California Edison
SERC	Software Engineering Research Center
SNL	Sandia National Laboratory
TAC	Technical Advisory Committee
TEAM	Transmission Economic Assessment Methodology
TRACE	Transfer Capability Evaluation
VAR	Voltage-Ampere Reactive
WAMS	Wide Area Measurement Systems
WAPA	Western Area Power Administration
WECC	Western Electric Coordinating Council
WSCC	Western States Coordinating Council